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ASSESSMENT OF HEAVY METALS POLLUTION IN THE UPPER ARKANSAS RIVER OF COLORADO

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16. ABSTRACT

Portions of the upper Arkansas River of Colorado are affected by heavy metal-laden inflows which are remnant of the mining era of the late 1800's. The heavy metal pollution results in a significantly impoverished stream biota in several areas. Historically, river flows which dilute heavy metal concentrations were not has high as these occurring since transmountain diversions began, so it is possible that the concentration of heavy metals in the river was higher in the past. Nevertheless, based on studies of water quality, accumulation of heavy metals in river sediments, species diversity indices, fish populations, and concentration of heavy metals in aquatic organisms at 11 sampling stations in an 18-mile (28.968-km) reach, conditions for aquatic life in the upper Arkansas River of Colorado are described as poor. Within this reach of river, there are three major sources of heavy metal inflow: Leadville Drain, California Gulch, and diffuse flows in an area between the inflows of Lake Fork and Lake Creek. California Gulch is by far the largest contributor of heavy metals. In each instance at varying distances from the pollution source, there is a downstream inflow of relatively clean water. These clean water inflows in two of the three cases result, in part, from the transmountain diversions. In the future, most of these two freshening flows will be diverted, which could cause the heavy metal inflow from California Gulch and Leadville Drain to be carried along a greater stretch of the Arkansas River. (56 ref)

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September 1975

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UNITED STATES DEPARTMENT OF THE INTERIOR * BUREAU OF RECLAMATION

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This report was developed as a result of a study requested by the Bureau of Reclamation's Lower Missouri Region and Fryingpan-Arkansas Project. Dr. D. A. Hoffman, formerly of the Bureau of Reclamation; and L. M. Finnell of the Colorado Division of Wildlife, Fort Collins, were the sources of unpublished data from 1971 to 1973 included in this report. D. L. Gallat of Colorado State University identified invertebrates collected in 1974, and calculated indices from these collections. Personnel from the Colorado Division of Wildlife and Dr. Eric Bergersen of the Fish and Wildlife Service Colorado Cooperative Fishery Unit at Colorado State University assisted in collecting fish. Special thanks to Mr. Homer Huntsinger, the property owner, and the American Sportsman Club, who lease the land, for allowing samples to be obtained at station AR-9.

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INTRODUCTION

The purpose of this study was to determine the magnitude of the heavy metal contamination in the upper Arkansas River and to locate specific problem areas.

This study is restricted to the assessment of heavy metal water quality problems in the Arkansas River from above the confluence of Leadville Drain to the confluence of Lake Creek. The periodic table identifies heavy metals as group B metals, while a recent international conference on heavy metal pollution at Vanderbilt University identified heavy metals as any element heavier than iron. The heavy metals referred to in this study include copper, iron, zinc, lead, molybdenum, and manganese.

The parameters included in the study are:

1. Existing historical water-quality data.

2. Field collections and analyses which were performed monthly from April through November 1974:

    a. Water.—Complete chemistry and heavy metals.

    b. Bottom sediment.—Heavy metals.

    c. Bottom organisms.—Diversity index and heavy metals.

    d. Fish.—Species and heavy metals (collected only in September).

The Fryingpan-Arkansas Project is located in central and southeastern Colorado (fig. 1). The project involves a transmountain diversion of water, requiring features on both the east and west slopes of the Continental Divide. Water from the Colorado River Basin will be diverted for beneficial and consumptive uses in the Arkansas River Basin in Colorado. The imported water will provide supplemental irrigation, municipal and industrial water, and enable power generation.

The collection and diversion facilities are being built in a mountainous and primitive area above an elevation of 10,000 feet on the headwaters of the Fryingpan River on the west slope of the Continental Divide. West slope features include the following:

1. Ruedi Dam and Reservoir.—Ruedi Dam is an earthfill structure on the Fryingpan River east of Basalt, Colo., which provides water for replacement and other beneficial uses on the west slope.

2. Collection System and Boustead Tunnel.—The collection system consists of three main parts: The North Side System, the South Side System, and Boustead Tunnel; all integrated to divert water across the Continental Divide.

The service area of the project is the Arkansas River Valley. Major east slope features include the following:

1. Turquoise Lake and Sugar Loaf Dam.—This reservoir collects water diverted through Boustead Tunnel.

2. Mt. Elbert Canal.—Mt. Elbert Canal will transfer project water from Turquoise Lake to the Mt. Elbert Powerplant at Twin Lakes.

3. Twin Lakes and Twin Lakes Dam.—The capacity of Twin Lakes will be increased by constructing a new earthfill dam. The reservoir will store and regulate the flow of Lake Creek and water discharged from the Mt. Elbert Powerplant.

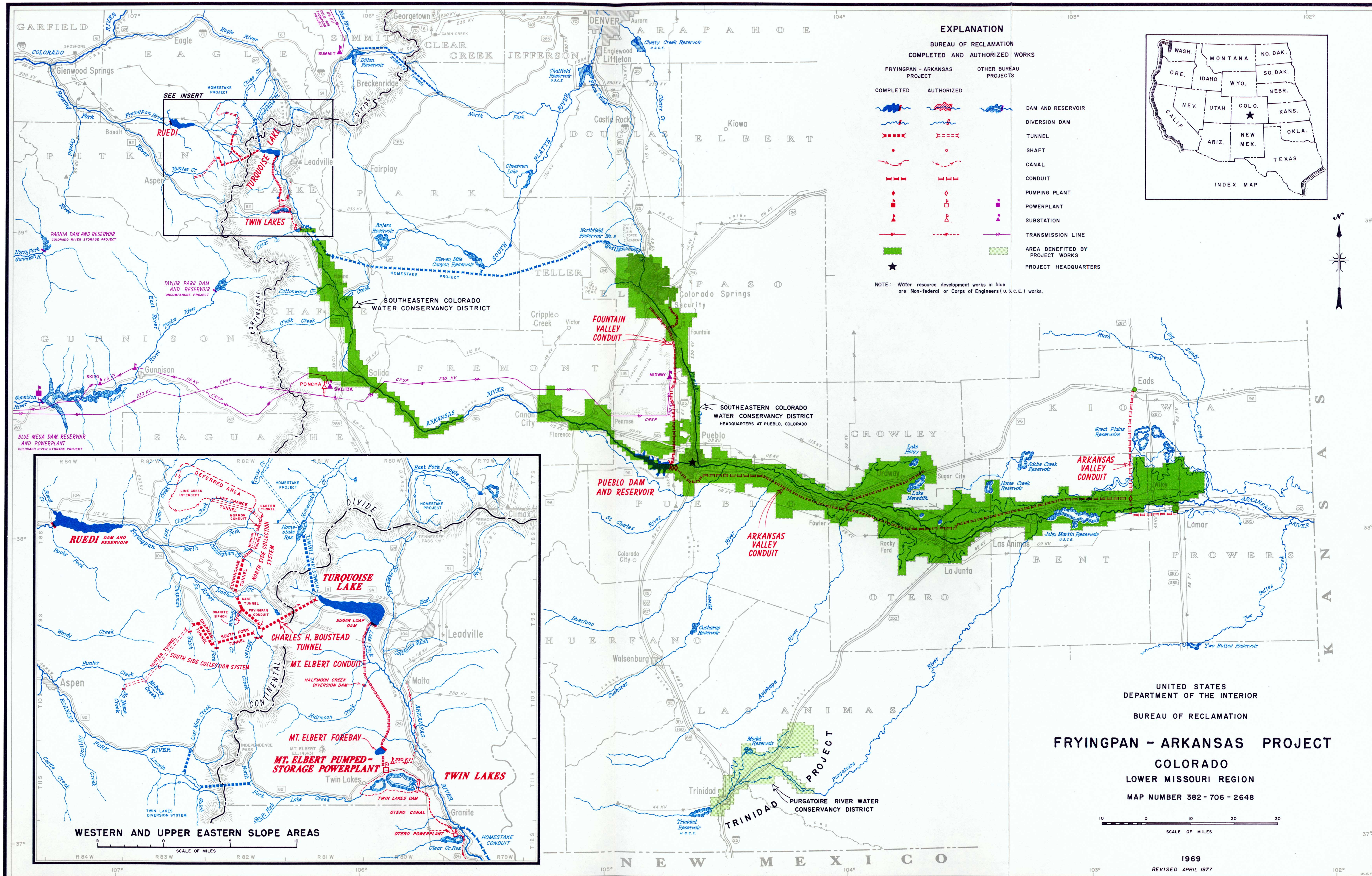
4. Otero Canal.—This canal will transfer water from Twin Lakes to the Otero Powerplant at Clear Creek Reservoir.

5. Clear Creek Reservoir.—Clear Creek Reservoir will regulate project flows to the Arkansas River.

6. Pueblo Dam and Reservoir.—This earthfill dam will create the largest reservoir on the Fryingpan-Arkansas Project.

SUMMARY

Based on data resulting from analyses of water, sediment, invertebrate, and fish collections made from 11 sampling stations from April through November 1974, in the upper Arkansas River, Colorado, there are three main areas of impact from heavy metal input. These include: (1) Leadville Drain and the sewage outflow from a trailer park; (2) outflow from California Gulch; and (3) diffuse sources between sampling stations AR-5 and AR-7. The heavy metal outflow from California Gulch is the most damaging to aquatic life in the river. The effect of the heavy metal input of Leadville Drain is not as extreme as concentrations of metals in the drain indicate; however, the sewage inflow, which is about the same magnitude, may be a mitigating factor. Any treatment of one flow without regard to the other, or any



EXPLANATION
BUREAU OF RECLAMATION
COMPLETED AND AUTHORIZED WORKS
FRYINGPAN - ARKANSAS PROJECT
OTHER BUREAU PROJECTS
COMPLETED
AUTHORIZED
DAM AND RESERVOIR
DIVERSION DAM
TUNNEL
SHAFT
CANAL
CONDUIT
PUMPING PLANT
POWERPLANT
SUBSTATION
TRANSMISSION LINE
AREA BENEFITED BY PROJECT WORKS
PROJECT HEADQUARTERS
NOTE: Water resource development works in blue are Non-federal or Corps of Engineers (U.S.C.E.) works.
INDEX MAP
SEE INSERT
RUEDI
TURQUOISE LAKE
TWIN LAKES
SOUTHEASTERN COLORADO WATER CONSERVANCY DISTRICT
FOUNTAIN VALLEY CONDUIT
SOUTHEASTERN COLORADO WATER CONSERVANCY DISTRICT HEADQUARTERS AT PUEBLO, COLORADO
PUEBLO DAM AND RESERVOIR
ARKANSAS VALLEY CONDUIT
ARKANSAS VALLEY CONDUIT
TRINIDAD PROJECT
PURGATOIRE RIVER WATER CONSERVANCY DISTRICT
PAONIA DAM AND RESERVOIR
TAYLOR PARK DAM AND RESERVOIR
BLUE MESA DAM, RESERVOIR AND POWERPLANT
HOMESTAKE PROJECT
NEW MEXICO
KANSAS
WESTERN AND UPPER EASTERN SLOPE AREAS
RUEDI DAM AND RESERVOIR
TURQUOISE LAKE
CHARLES H. BOUSTEAD TUNNEL
MT. ELBERT CONDUIT
MT. ELBERT FOREBAY
MT. ELBERT PUMPED-STORAGE POWERPLANT
TWIN LAKES
SOUTH SIDE COLLECTION SYSTEM
NORTH SIDE COLLECTION SYSTEM
SCALE OF MILES
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
FRYINGPAN - ARKANSAS PROJECT
COLORADO
LOWER MISSOURI REGION
MAP NUMBER 382 - 706 - 2648
SCALE OF MILES
1969
REVISED APRIL 1977

GPO 840-550

increase in the drain's flow, should be viewed with caution. The present damaging effect from the heavy metal input of California Gulch is being somewhat mitigated by the Lake Fork and Halfmoon Creek flows, which are now higher than they were historically. Any decrease in mitigating flows would be expected to extend the effect of the gulch downstream. This conclusion is in agreement with the findings of Moran and Wentz (1974).

Although the diffuse sources of heavy metal input are not extremely damaging at present, a large decline in the Lake Fork and Halfmoon Creek flows could be expected to compound the problem by allowing the effect of California Gulch to extend downstream. The Lake Creek inflow counteracts the deleterious effect of the diffuse contaminant sources. Reduction of this flow would be expected to extend the heavy metal influence even farther downstream.

Because of the lack of data on expected flows under project conditions, it is impossible to quantify the effects discussed. Operational hydrology should be added to these data at the first opportunity. An alternative to maintaining the present mitigatory flows is to treat the heavy metal sources. Leadville Drain effluent at present is not the major problem; however, an increased drain flow and/or lack of sewage buffer could be expected to change this situation. Treatment of California Gulch effluent would remove the principal point source of pollution in the entire area and should, therefore, be considered prior to treatment of the Leadville Drain effluent. The diffuse sources are difficult to deal with directly. To maintain present water quality in this area without the dilution effect of Lake Fork and Halfmoon Creek would necessitate eliminating California Gulch as a pollution source.

APPLICATION

The results of this study will be of interest to anyone involved in the assessment of water pollution in mining areas, and of particular interest to those concerned with the problem of heavy metals contamination of streams in the Colorado mineral belt.

HISTORICAL REVIEW

The upper Arkansas River Basin lies astride the Colorado mineral belt which extends across the State in a northeast to southwest direction, beginning near Boulder and continuing through the San Juan Mountains. This belt was formed chiefly during the Laramide Orogeny of Tertiary Age with some later Oligocene enrichment by mineral-laden intrusive dikes and gaseous emanations (Wentz, 1974). The mineral belt in the study area is about 50 miles (80.467 km) wide.

Heavy metal pollution of the upper Arkansas River and its tributaries is thought to have begun in 1859 with the discovery of placer gold along California Gulch (Ubbelohde, 1964). This placer deposit, located east of present-day Leadville, was mined about 4 years. From 5 to 7 million dollars worth of gold was panned from this deposit (Ubbelohde, 1964). In 1859, gold in quartz veins was discovered at the Printers Boy Mine just above the beginning of the California Gulch on the west side of the Mosquito Range. This and a few other quartz vein gold mines in the area were worked for a few years, then abandoned. In 1874, the Carbonate Hills mines were discovered about 4 miles (6.4374 km) northeast of Leadville (Ubbelohde, *et al.*, 1971). These mines contained some gold, but mainly silver and sulfide ores of copper, iron, lead, and zinc. This discovery started the great silver boom. Mines were worked vigorously until silver prices fell in 1893. During this period, 1874 to 1893, the hillsides to the east, north, and west of Leadville, which also contained rich sulfide deposits of silver, were also heavily mined. The waste rock and low-grade ore materials were deposited in tailing piles alongside and in the nearby gulches and creekbeds. The sulfide ores required roasting and smelting to obtain the silver. Other metals had no economic demand at that time; thus, they were left in tailing piles. The first smelter began operation at Malta in about 1877 (Ubbelohde, *et al.*, 1971; Coquoz, 1971). Soon many more smelters began operation in the area. The smelters, at first, used the native timber for firing their furnaces. As this fuel supply was exhausted, coal was hauled in by wagon trains and railroads. Removal of trees from the hillsides allowed rapid erosion with consequent pollution of the streams. The waste and slag material from the smelters were discarded in nearby gulches and creekbeds. Smelters were operating night and day, resulting in continuous air pollution from smelter smoke. Smoke contamination intensified corrosion of exposed metals and caused vegetation to die, as well as lung diseases in human and other animal life (Ubbelohde, *et al.*, 1971). The 1893 fall of silver prices caused many of the marginal operating mines to be abandoned. The mines, many of which had to be pumped continuously because they were below the water table, soon filled with water and overflowed, washing the highly oxidized tailing piles into the gulches and creeks. Recovery from the 1893 depression was very slow. Significant recovery did not occur until World War I, when mining operations resumed to obtain strategic wartime metals. This surge in mining continued through the early and mid-1920's, and again declined during the 1930's.

The carbonate mining area just east of Leadville was dewatered during the early 1920's by construction of drainage tunnels. Cantebury Tunnel and Yak Tunnel were two of the earlier drainage tunnels used for this purpose (P. O. Abbot, pers. comm.). The beginning of World War II again spurred metal mining activity. Climax reopened the large molybdenum deposit atop Fremont Pass, 12 miles (19.312 km) east of Leadville at an elevation of 11,300 feet (3444.2 m). This deposit was first discovered and previously worked only temporarily during and shortly after World War I for the steel hardening alloy mineral, molybdenum. Another drainage tunnel in Carbonate Hill, now called Leadville Drain, was begun in 1940, and completed to its present length during the Korean War (N. B. Bennett III, pers. comm.). Cantebury Tunnel Drain, located to the northeast of the Carbonate Hill area on the southern slope of the East Fork, is now collapsed. No drainage water from it can be detected flowing into the East Fork.

In May 1923, the Yak (A. A. Blow) Tunnel, which presently contributes to the flow in California Gulch, was built. At first, it produced a flow of 15,000 gal/min (56,775 l/m). The following June the flow was still producing 8,700 gal/min (32,930 l/m). The tunnel was completed to a distance greater than 20,000 feet (6,096 m). After receiving drainage water from Yak Tunnel, California Gulch flows through numerous mine and smelter tailing piles and finally into the Arkansas River.

At the present time, the only active mining operation is at the Climax molybdenum mine. No known contamination is released from its operation down the East Fork.

About 64 miles (103 km) of stream in the upper Arkansas River drainage are polluted by heavy metals (Wentz, 1974). Mine drainage water, and surface and underground seepages through the old mine and smelter tailing piles continue to pollute the Arkansas River and its tributaries. Presently, the three worst pollutant sources are Yak Tunnel (California Gulch), Leadville Drain, and St. Kevin Gulch. Heavy metal contaminants are chiefly manganese, iron, copper, zinc, and cadmium, with some locally heavy concentrations of sulfates. Water from Yak Tunnel and California Gulch are acid, others tend to be neutral or slightly alkaline. In certain areas of the Arkansas River, water is harmful to aquatic life. There are reports (D. Heinz, pers. comm.) that horses in the area have had difficulties in foaling which the ranchers attribute to heavy metal pollution. Jones (1940) noted similar problems in Welsh mining districts where the pastures and water were zinc polluted. Heavy metal pollutants also cause corrosion of steel and concrete structures.

For more than a hundred years, this area of Colorado has depended on mining as its chief source of income, but not until recently have studies began to determine its harmful effects. The following is a quote from Moran and Wentz (1974) based on their recent studies of the area:

> "Thus, it appears that the major contributor of metals and acid to the Arkansas River is California Gulch. As a result there is a significant deterioration of water quality at least down to the inflow of Lake Creek. Further degradation of water quality in the Arkansas River could result if planned diversions of water from Halfmoon Creek and the Lake Fork of the Arkansas are implemented by the U.S. Bureau of Reclamation. Such measures would greatly reduce the flow of these streams, which presently help to dilute the metals and acid from California Gulch."

Table 1 summarizes the known literature pertinent to understanding the background for this study. Five time periods based on the changes in flow and pollution input to the river are given.

Time period I represents the era before mining when the river and its tributaries were in a pristine state. There are no known data on water quality from this period. Time period II begins when mining began and ends when the first transmountain diversion began in 1910. This period is characterized by heavy mining and smelter activity which resulted in heavy air and water pollution. It may be speculated that the upper Arkansas River was relatively denuded of its aquatic life during this time. Data on the history of mining activity of the area are available for this time period. Time period III began in 1910 when the first transmountain diversion augmented the Arkansas River flow and ended in 1968 when the first major water transmountain diversion occurred. During time period III, mining activity continued especially during wartime. Some water-quality data are available for the latter part of this period. During this period the following transmountain diversions were completed:

1. Ewing	October 1910
2. Busk Ivanhoe (Carlton Tunnel)	June 1925
3. Columbine	October 1930
4. Works Ditch	October 1931
5. Roaring Fork (Twin Lakes Tunnel)	1935
6. Works Ditch extended	August 1952

Table 1.—*Upper Arkansas River flow history*

Period	Reference sources	Type of data available
I. [Native flow prior to mining activity in 1859]	None known	None known
II. [Mining activity (1859) late 1850's to first water diversion (1910)]	Coquoz (1971)	Mining and smelter activity
	Ubbelohde, C. *et al.* (1971)	Mining and smelter activity
	Ubbelohde, C. (1964)	Mining and smelter activity
	Abbott, P. O. (pers. comm.)[1]	First water diversion
III. [First water diversion (1910) to major water diversion (1968)]	Ubbelohde, C. *et al.* (1971)	Mining activity, Yak Tunnel, Twin Lakes Tunnel
	USGS—Anonymous ( )	Water-quality data (flow rates, temperature, chemical data, etc.)
	Bennett, N. B., III (pers. comm.)[2]	Mining and drainage tunnel data
	Abbott, P. O. (pers. comm.)[1]	Transmountain diversion and flow rate data
IV. [Major water diversion (1968) to proposed operation of Mt. Elbert Canal (Oct. 1979)]	USGS—Anonymous (1963-74)	Water-quality data (flow rates, temperature, chemical analyses, etc.)
	Wentz (1974) and his cited references	Water-quality data, drinking water standards, water criteria for aquatic biota, chemical data, visual observations, quality and semi-quality flora, and fauna, etc.
	Moran and Wentz (1974) and their cited references	Same as above for Wentz (1974)
	Bennett, N. B., III, (pers. comm)[2]	Geological data—mining and tunnel drainage activity
	Abbott, P. O. (pers. comm.)[1]	Transmountain diversions, waterflow past, present, and proposed
	Heinz, D. (pers. comm.)[3]	Agricultural information—impact of contamination on livestock and pastures in Leadville area
V. [Operation of Mt. Elbert Canal and Pumping Plant (1979) to operation of Otero Canal and Pumping Plant 1983)]	Proposed (no data)	Proposed (no data)

[1] P. O. Abbott, Hydrologist, Fryingpan-Arkansas Project, Bureau of Reclamation, Pueblo, Colorado.
[2] N. B. Bennett, III, Chief of Geology Branch, Lower Missouri Region, Bureau of Reclamation, Denver, Colorado.
[3] D. Heinz, District Ranger, Leadville District, San Isabel National Forest, Leadville, Colorado.

Time Period IV began in 1968 when Homestake Tunnel, the first major transmountain water diversion tunnel was completed. Homestake Tunnel water flows into the Arkansas River by way of Lake Fork. This tunnel, along with the Boustead Tunnel, which was completed in 1972, contributes significantly to Arkansas River flow. These flows tend to dilute heavy metal pollution. Water-quality and geological data are available for this time period. Time period V will begin upon completion of the Mt. Elbert Canal. At that time most of the water presently flowing down Lake Fork will Be diverted by the Mt. Elbert Canal into Twin Lakes, returning to the Arkansas River via Lake Creek. Upon completion of the Otero Canal, the water will be diverted to Clear Creek Reservoir, returning to the Arkansas River via Clear Creek. Thus, flow in the Arkansas River from its confluence with Lake Fork to its confluence with Clear Creek near Granite will be reduced.

METHODS AND MATERIALS

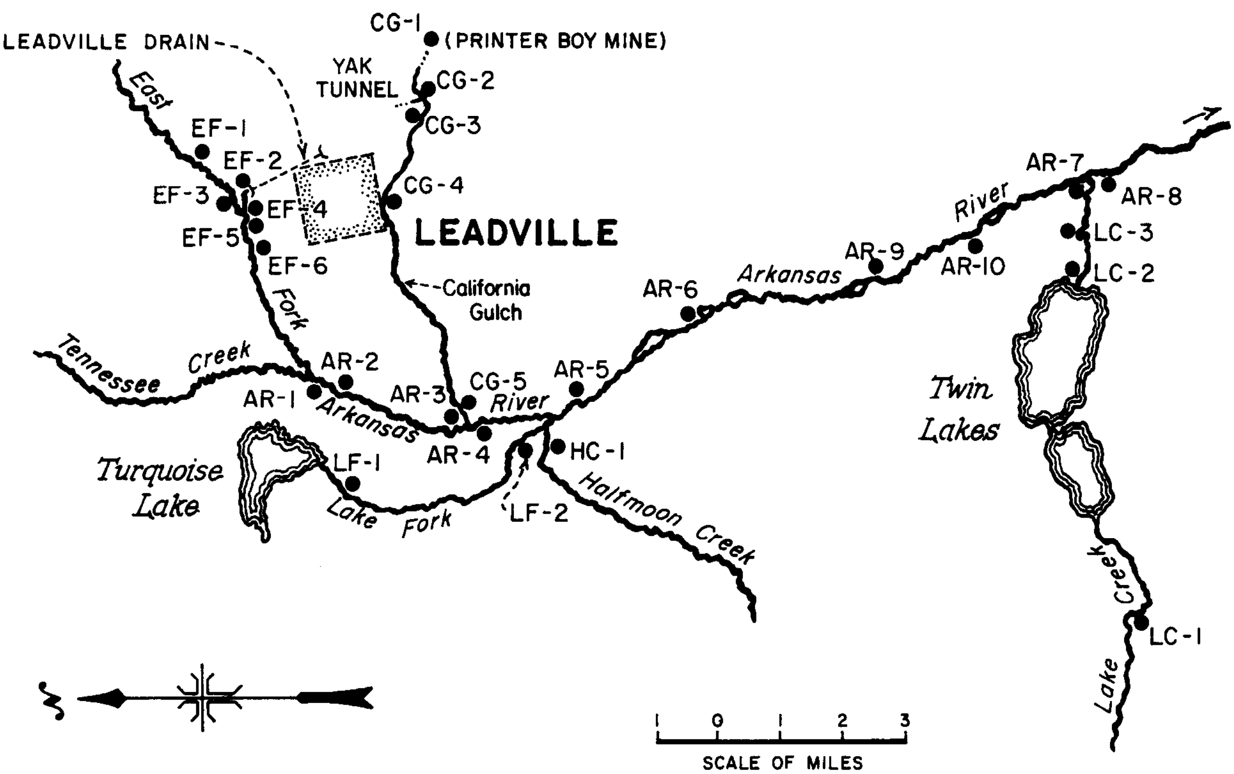
Description of the area

General.—The area studied (see inset on fig. 1) lies in the Southern Rocky Mountain Physiographic Province just east of the Sawatch Range whose crest forms the Continental Divide. Mt. Elbert, Colorado's highest peak with an elevation of 14,431 feet (4398 m) above m.s.l. (mean sea level) is located in this range. The Mosquito Range lies immediately to the east and generally parallel to the Sawatch Range in the area studied. The area is characterized as a high mountain basin with a natural dendritic drainage pattern opened to the south. The Arkansas River in the study area flows in a broad valley which has been subjected to repeated glaciation. Chief uses of the valley today are mining on the upper slopes and grazing in the bottom lands. Some of the Arkansas River tributaries originate from small alpine lakes while others, like the river itself, begin on mountain slopes. Flow is characterized by high late spring and early summer flows cascading down the steep rocky channels and then receding to a more stabilized natural or base flow for the remainder of the year. Many of the gulches dry up during early summer and fall, though some are known to carry seepage to creek channels and to the Arkansas River. Diverted flows from the western slope augment the river's flow considerably below Turquoise Lake and Twin Lakes. Elevations of the area studied range from 10,000 feet (3048 m) above m.s.l. at the most upstream station to 9000 feet (2743 m) above m.s.l. at the station just below Lake Creek. Vegetation along the river in the study area consists mainly of grass and shrubs with very few trees. The shrubs include willow, sagebrush, bitterbrush, and common shadbush. Common forbs are silver lupine, fairy trumpet, sulfur flower, cranesbill, and squaw current along with numerous wheat grasses, fescues, foxtails, and sedges.

Specific areas studied.—Stations where data were gathered are designated (from upstream to downstream) EF-3, EF-5, AR-1, AR-3, AR-4, AR-5, AR-6, AR-9, AR-10, AR-7, and AR-8. Figure 2 shows the approximate location of the sampling stations. Figures 3 to 10 are aerial photographs of the area studied. EF-3, the uppermost station is about 100 yards (91.44 m) above the inflow of Leadville Drain (fig. 11). Water at this station flows at a relatively even rate and is fresh and clean. Station EF-5 (fig. 12) is about 200 yards (182.88 m) below the confluence of the Leadville Drain. Leadville Drain contributes only 3 to 4 ft^3/s (0.085 to 0.1133 m^3/s) to the river, so that the flow at EF-5 closely resembles that at EF-3. These two stations are located in an area just north of Leadville near a trailer park. Sewage effluent, in some cases quite raw, enters the East Fork of the Arkansas River in proximity of its confluence with Leadville Drain. Sampling station AR-1 (fig. 13) is located at the Malta USGS streamflow gage about 200 yards (182.88 m) below the river's confluence with Tennessee Creek. Heavy willow thickets surround the stream at this site. Sampling station AR-3 (fig. 14) is located below the bridge over the Arkansas River on State Highway No. 300 which goes to the U.S. Fish and Wildlife Service's Leadville fish hatchery. This station is located about 300 yards (274.32 m) above the confluence of California Gulch and the Arkansas River. Sampling station AR-4 (fig. 15) is located about 1/2 mile (0.805 km) below the confluence of California Gulch and 3/4 mile (1.2 km) above the confluence of Lake and East Forks of the Arkansas River. The heavy metal-laden drainage from California Gulch is well mixed into the river at this point. Clarity of the water was poor at all sampling times. The banks of the stream are lined with willows and other shrubs, and the area is heavily grazed. Sampling station AR-5 (fig. 16) is located on the Smith Ranch about 1/2 mile (0.805 km) below the confluence of Lake and East Forks of the Arkansas River. At this point, flows become very irregular and at times are quite high because of the contribution of Lake Fork which carries transmountain diversion flows from Turquoise Reservoir. Water clarity is high at most times of the year because the influence of California Gulch is significantly diluted at this station. Grassland and thickets surround the stream, and the area is grazed. Sampling station AR-6 (fig. 17) is located at the Snowden Overpass on U.S. Highway No. 24. The river flows relatively fast and deep at this point and, as at AR-5, the flows vary widely over a season. Sampling station AR-9 (fig. 18) is located immediately upstream from a wooden bridge on the Pan-Ark property just east of U.S. Highway No. 24. The stream widens between AR-6 and AR-9, with willow and grassland again surrounding the stream. Sampling station AR-10 (fig. 19), is located about 200 yards (182.88 m) below the inflow of Box Creek from the west. At this point the river enters a canyon and becomes relatively more confined. Sampling station AR-7 (fig. 20) is located about 1/2 mile (0.805 km) above the confluence with Lake Creek which is the outflow from Twin Lakes. Steep gravel bluffs confine the river to a relatively deep, narrow channel. Sampling station AR-8 (fig. 21) is located about 1/2 mile (0.805 km) below the Lake Creek confluence. The high seasonal flows of Lake Creek result in a widely fluctuating flow pattern at this station. These flows result from the Twin Lakes Irrigation and Canal Company's transmountain diversion into Twin Lakes. This inflow acts as a dilutant of the more eutrophic and heavy metal-laden flow of the Arkansas River. Steep gravel banks line the stream and the vegetation consists of sagebrush, willows, and some cottonwood trees.

LOCATION MAP OF STREAM - SURVEY STATIONS

(FROM USGS MT. ELBERT AND HOLY CROSS QUADRANGLES)



LEGEND

EF-East Fork & Leadville Drain Stations (6)

CG-California Gulch & Yak Tunnel Stations (5

AR-Arkansas River Stations (10)

LF-Lake Fork Stations (2)

HC-Halfmoon Creek Stations (1)

LC-Lake Creek Stations (3)

Figure 2. Location map of stream-survey stations.

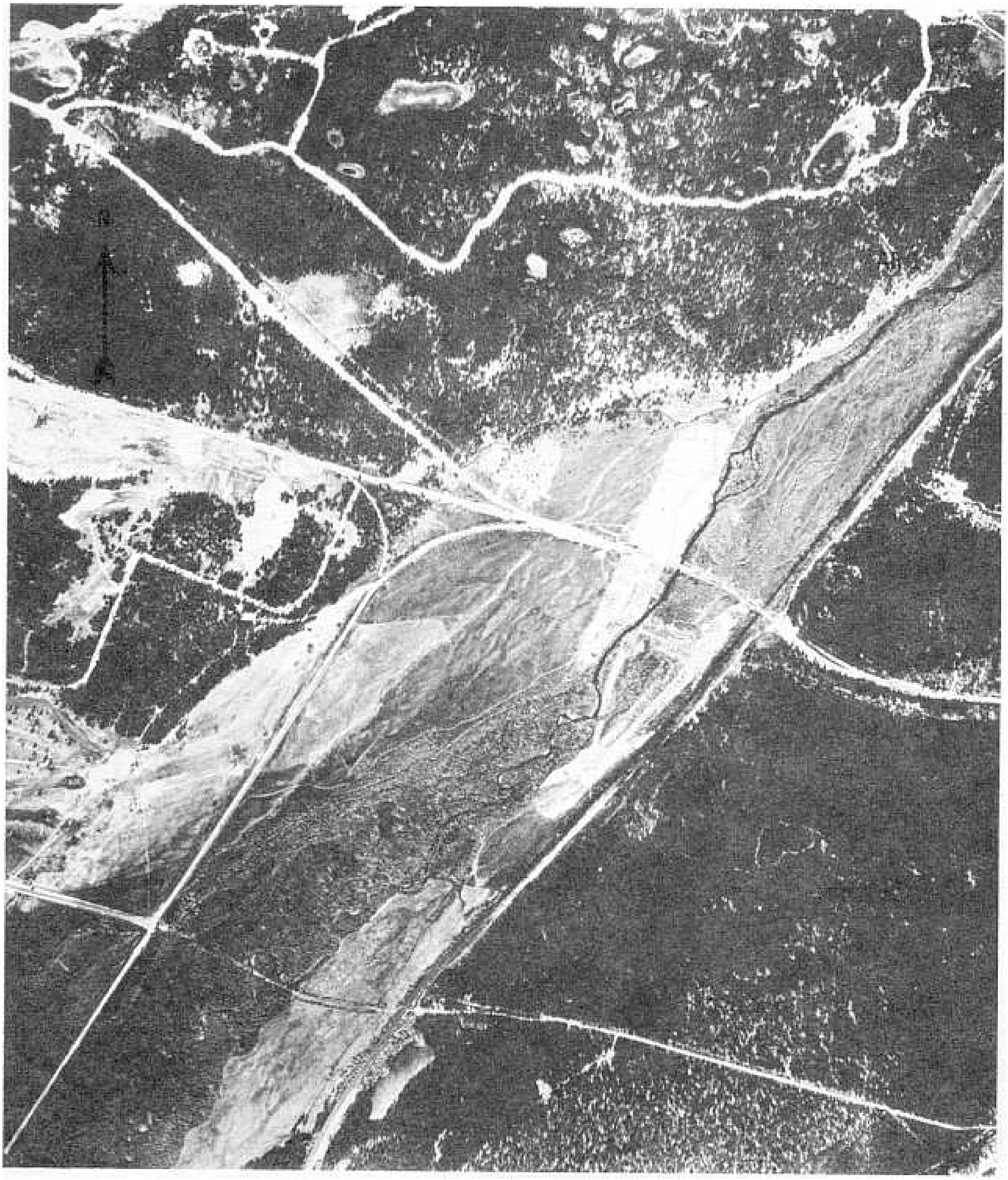


Figure 3. Aerial photo of upper Arkansas River: Station AR-1. Photo P382-D-75962

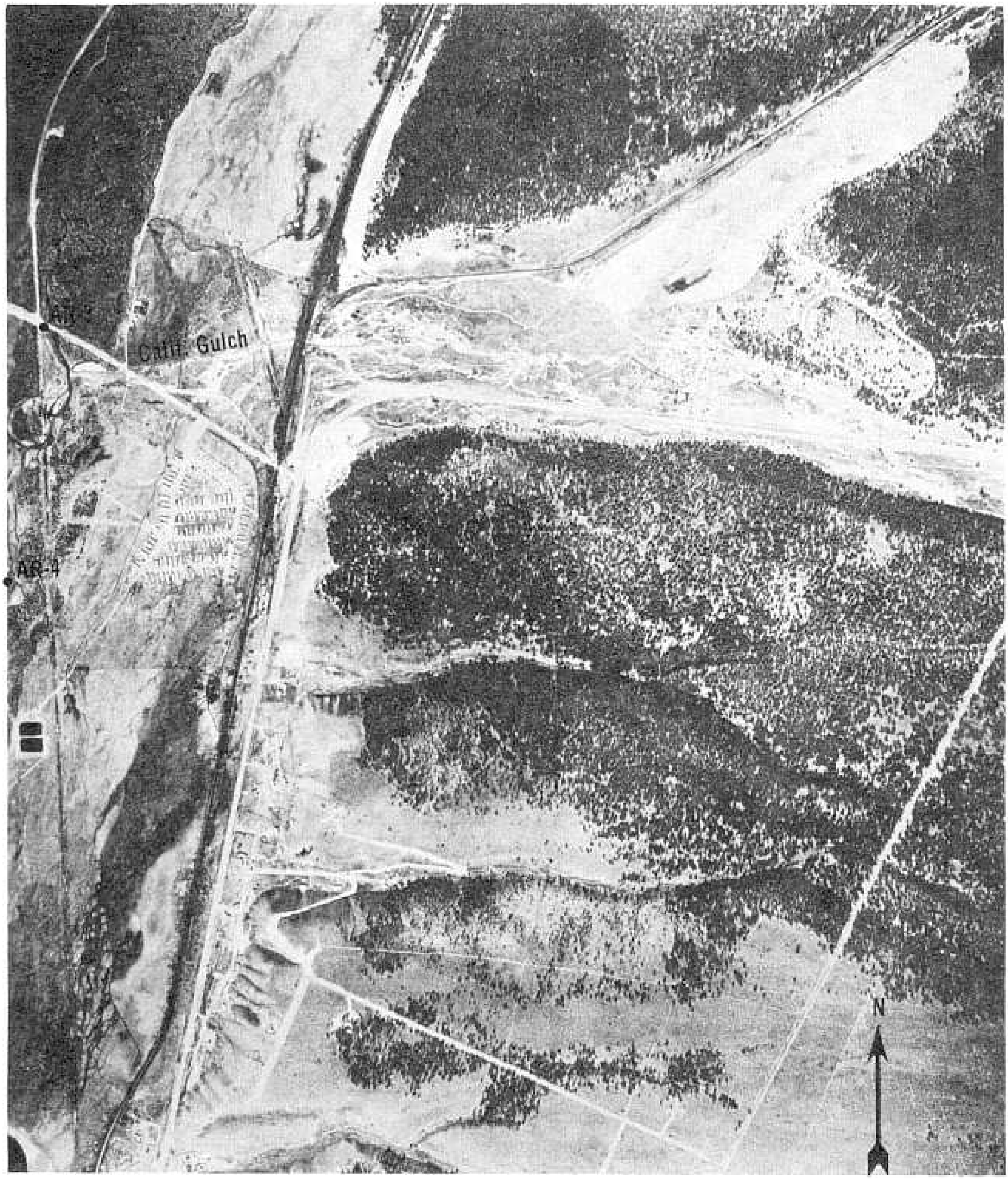


Figure 4. Aerial photo of upper Arkansas River: Stations AR-3 and AR-4. Photo P382-D-75961

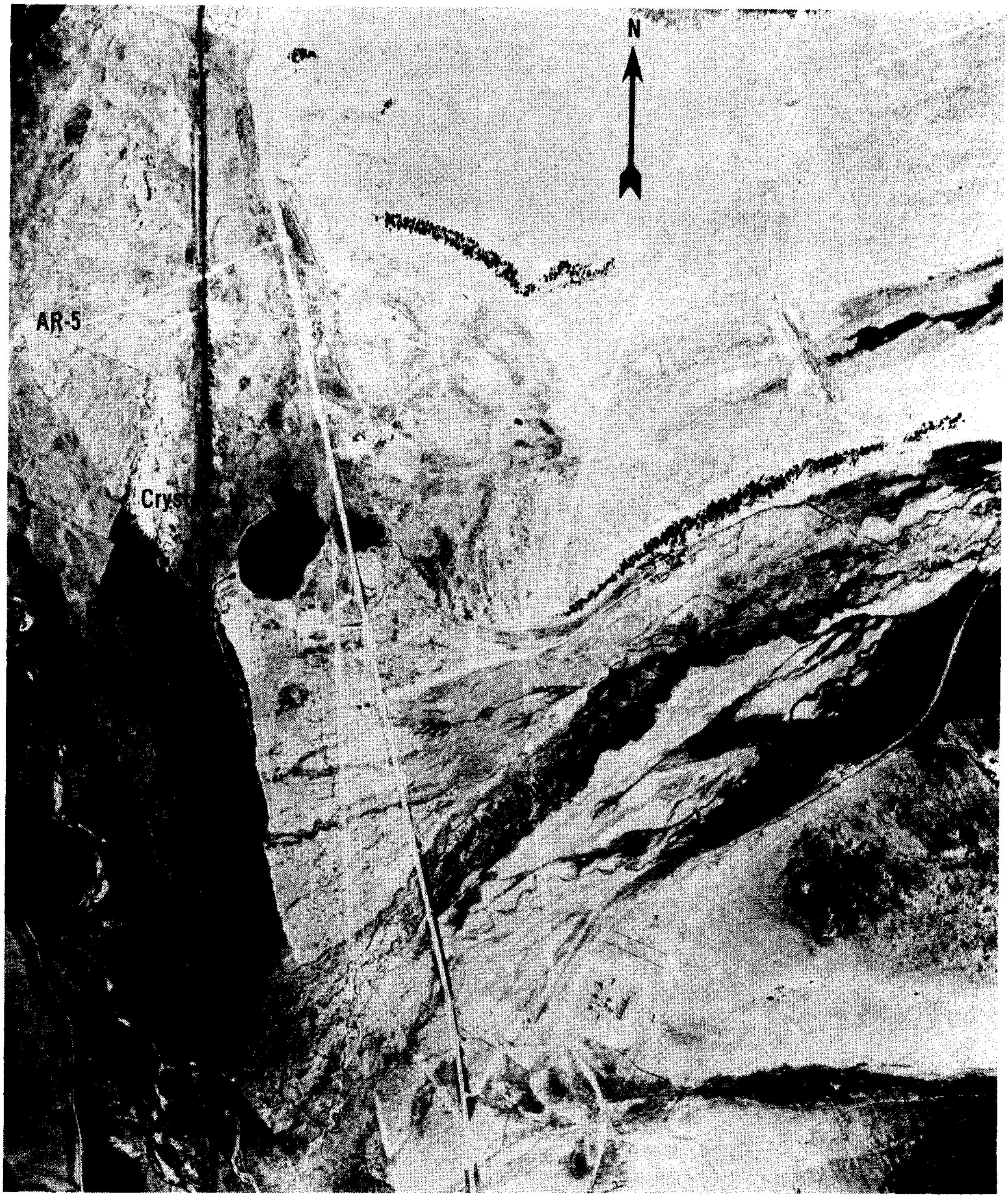


Figure 5. Aerial photo of upper Arkansas River: Station AR-5. Photo P382-D-75963

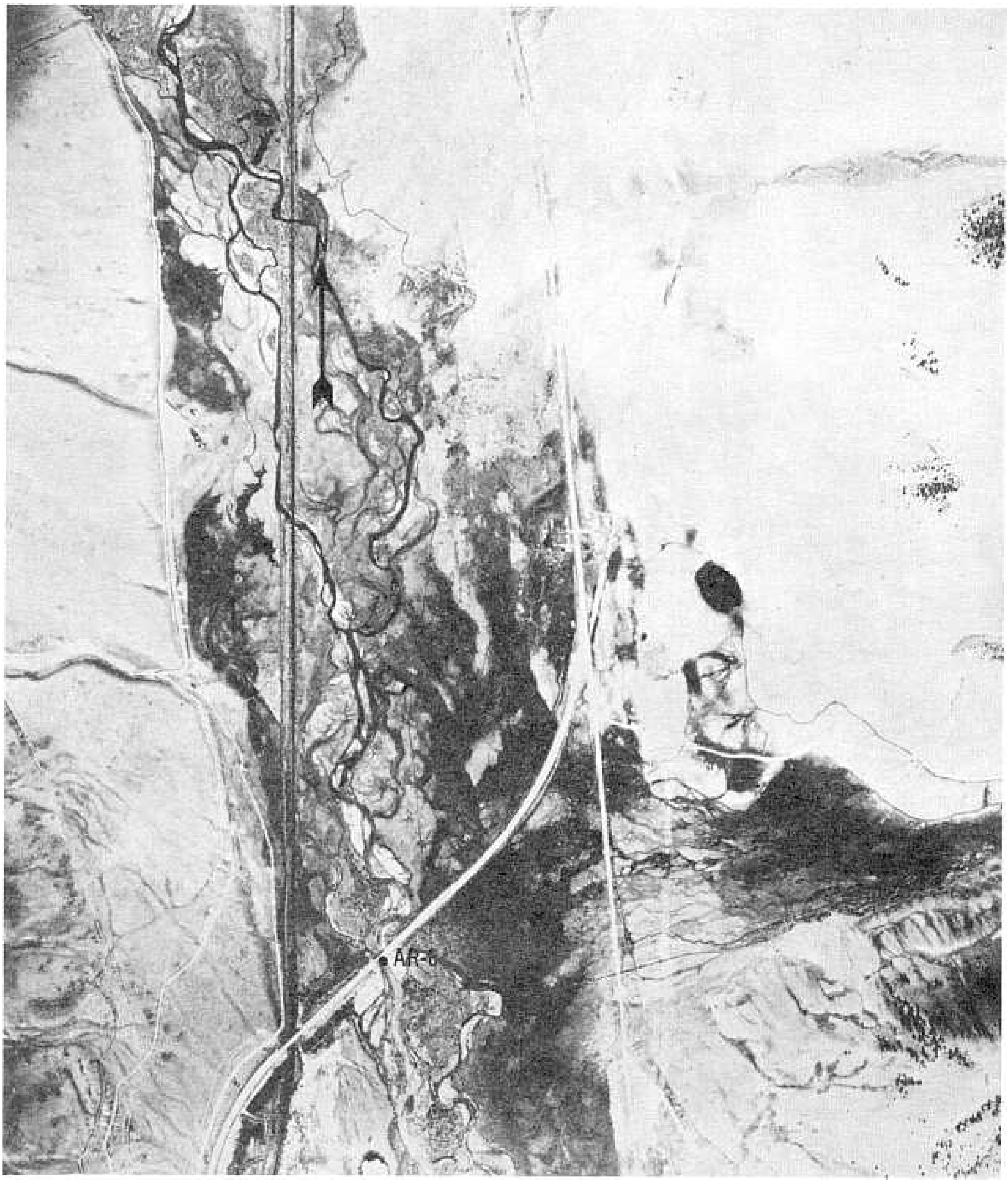
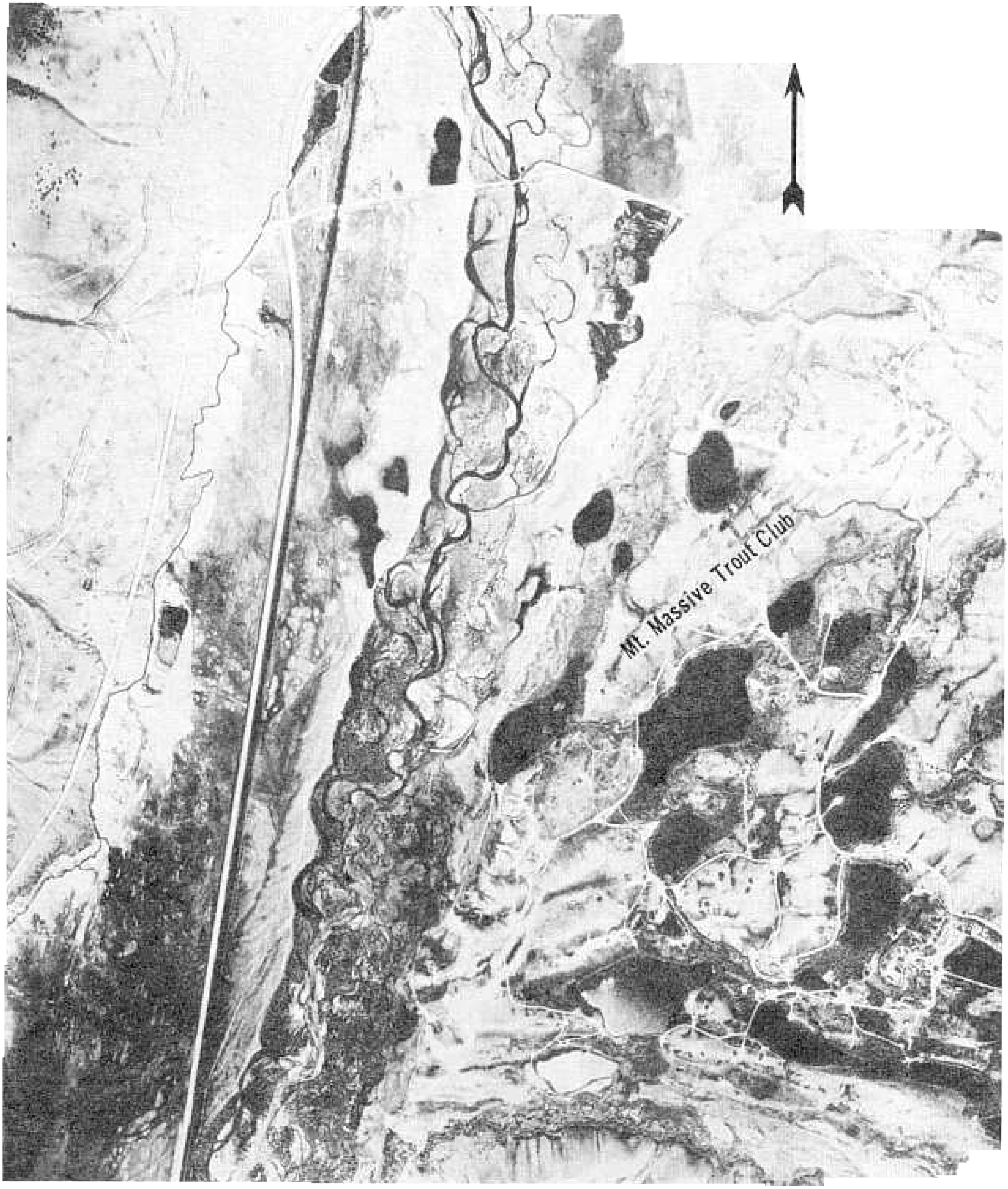


Figure 6. Aerial photo of upper Arkansas River: Station AR-6. Photo P382-D-75964



Massive Trout   ıoto P3B2

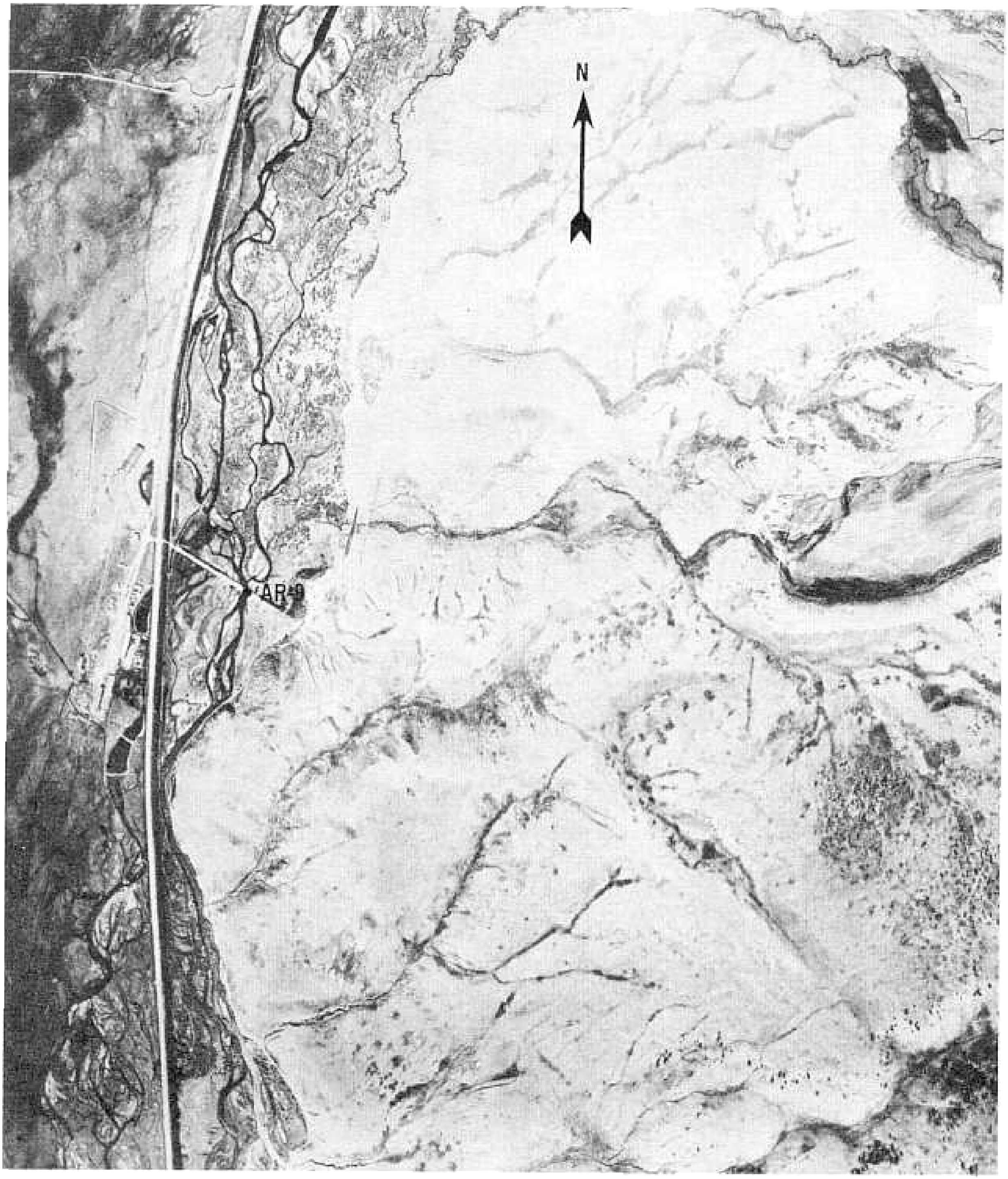


Figure 8. Aerial photo of upper Arkansas River: Station AR-9. Photo P382-D-75966

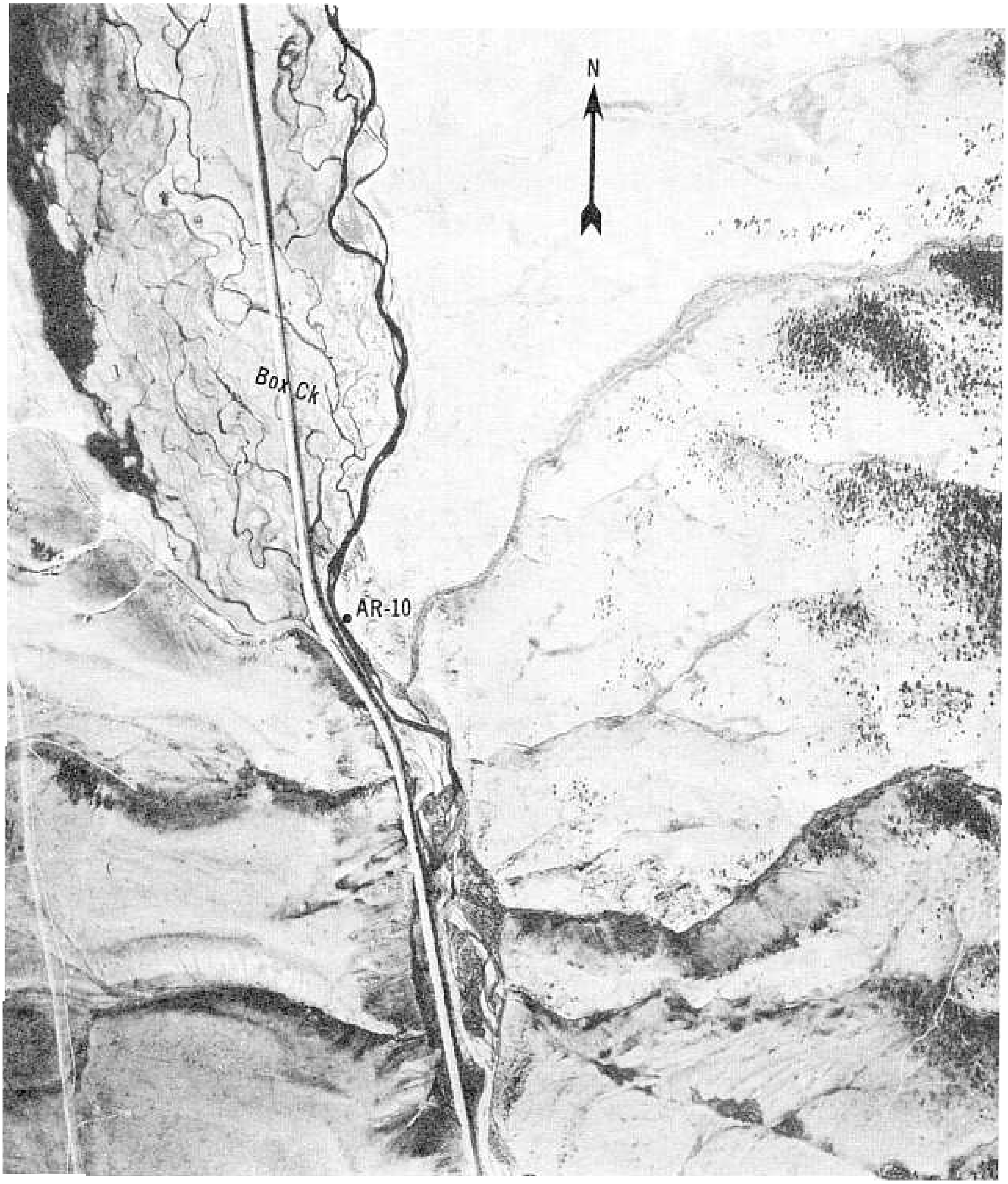


Figure 9. Aerial photo of upper Arkansas River: Station AR-10. Photo P382-D-76015

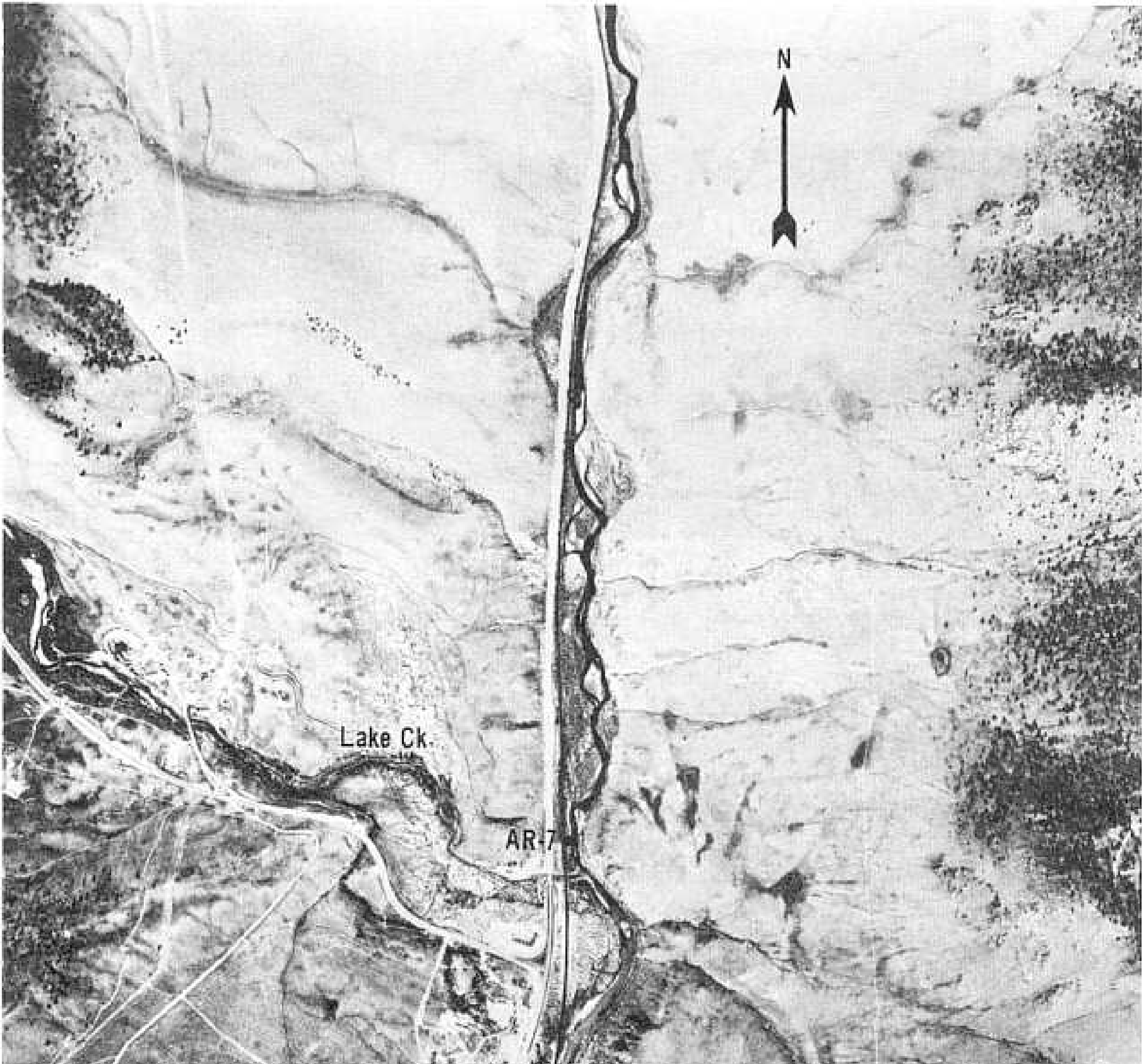


Figure 10. Aerial photo of upper Arkansas River: Stations AR-7 and AR-8. Photo P382-D-76014

Figure 11. East Fork of the Arkansas River looking upstream at station EF-3. Photo P382-D-76025 May 8, 1974

Figure 12. East Fork of the Arkansas River looking northwest (downstream is to the left) at station EF-5. Photo P382-D-76016 August 27, 1974

Figure 13. Arkansas River looking downstream at station AR-1. Photo P382-D-76017 May 8, 1974

Figure 14. Arkansas River looking downstream (left) at station AR-3. Photo P382-D-76018 May 8, 1974

Figure 15. Arkansas River looking upstream at station AR-4 below the inflow of California Gulch. Photo P382-D-76019 August 27, 1974

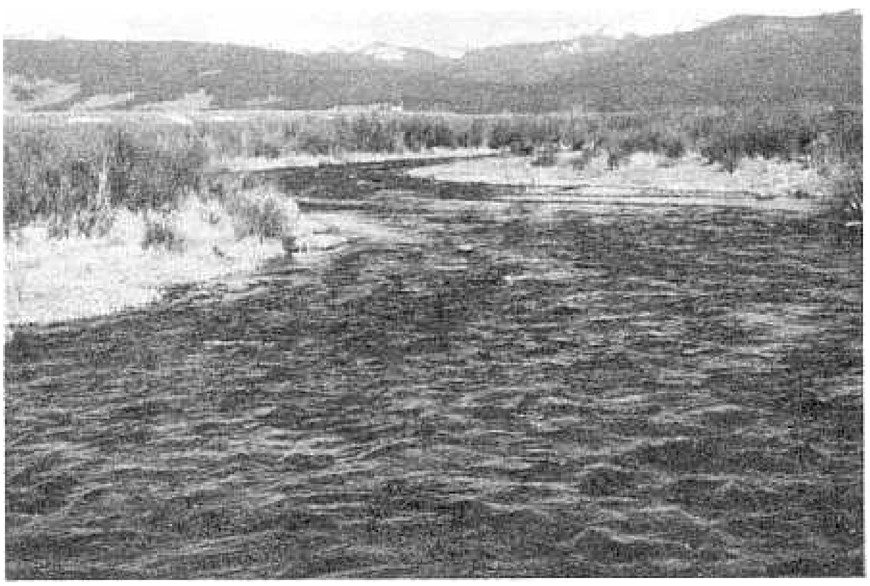


Figure 16. Arkansas River looking upstream at station AR-5 below the inflow of Lake Fork. Photo P382-D-76020 May 8, 1974

Figure 17. Arkansas River looking downstream at station AR-6 at Snowden Overpass. Photo P382-D-76021 May 8, 1974

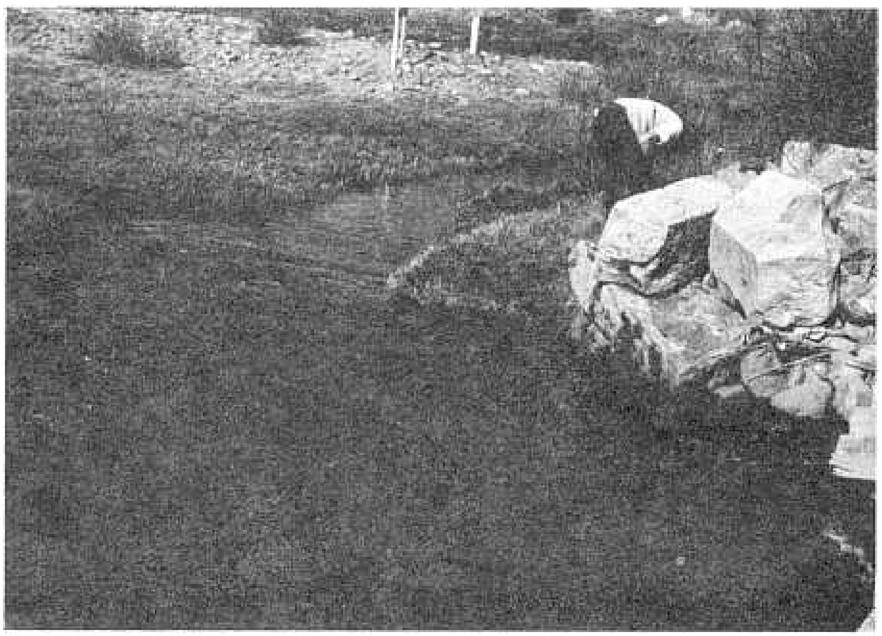


Figure 18. Arkansas River looking northeast (upstream is to the left) at station AR-9, the Pan-Ark Bridge. Photo P382-D-75960 May 8, 1974

Figure 19. Arkansas River looking upstream at station AR-10, just below the confluence of Box Creek. Photo P382-D-76022 May 8, 1974

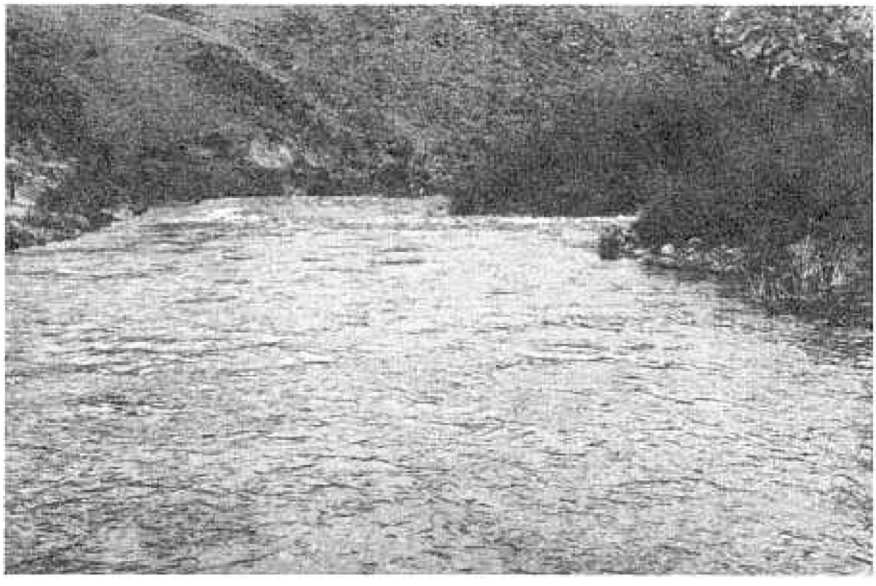


Figure 20. Arkansas River looking downstream at station AR-7 just above the confluence of Lake Creek. Note inflow of Lake Creek in right center of photo. Photo P382-D-76023 May 8, 1974

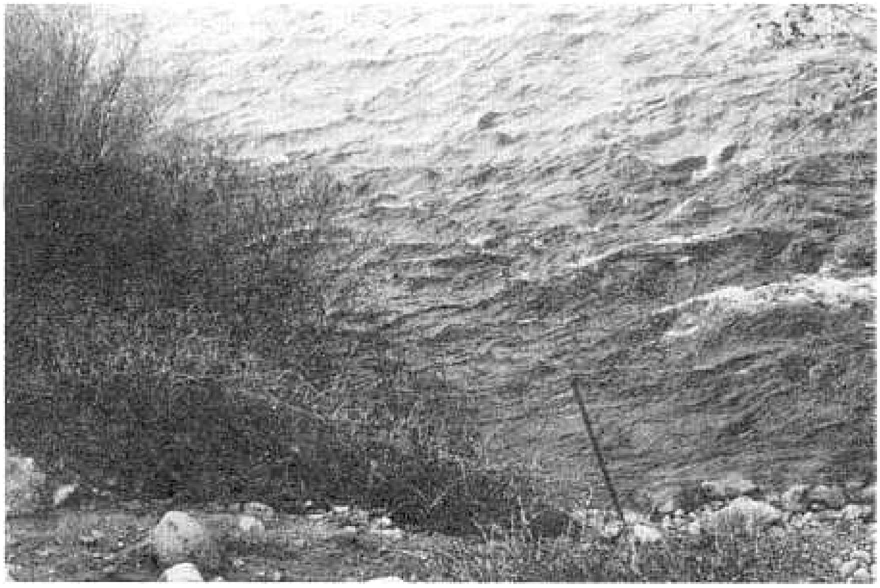


Figure 21. Arkansas River looking northeast (upstream is to the left) at station AR-8 just below confluence of Lake Creek. Photo P382-D-76024 May 8, 1974

Data Collection

Physical-chemical.—Data were collected monthly in the field from April through November 1974, at each of the stations previously described. The following is a description of the monthly procedure. A quart of water was collected to be analyzed for water quality. A pint of water was collected for heavy metal analysis to which 1 ml of nitric acid was added to keep metals in solution. This sample was not filtered prior to the addition of nitric acid; thus, analytical results reflect total dissolved and suspended metals. In addition, water chemistry analyses were obtained for 23 stream stations in the Leadville area from 1971 through 1973. These data, as well as some data collected in 1969 by D. A. Hoffman, formerly with the Bureau of Reclamation, and L. M. Finnell of the Colorado Division of Wildlife, are listed in appendix A. Chemical data presented here are limited both as to number of samples and time period, and should, therefore, be viewed as indicative rather than definitive. Air and water temperatures were measured with either a Yellow Springs temperature/dissolved oxygen probe or a mercury thermometer. Thermographs were maintained in 1973 at stations LF-1 (just below the outlet of Sugar Loaf Dam), AR-1, AR-5, and AR-7. A continuous 136-day record of temperatures was obtained at each station and reduced to a computer card deck of 2-hour readings. The data were summarized as average daily temperature cycles for each month at each station. Dissolved oxygen was measured either with a Yellow Springs dissolved oxygen probe or by the Hach modified Winkler method. Conductivity was measured in the field with a Hach conductivity probe and checked in the laboratory. Hydrogen-ion concentration (pH) was measured with a Beckman pH probe. Stream velocity readings were made at or near the artificial substrate sampler using a Price current meter. Sediment samples were composites of several samples from different areas of the stream bottom at each station. Sediment samples were collected only in May, June, July, and November, 1974.

Invertebrates.—The macroinvertebrate community was sampled using a modified version of the basket-type artificial substrate sampler described in the thirteenth edition of "Standard Methods" (1971). In this case, the cylindrical commercial barbeque basket was filled with redwood bark chips averaging about 3 inches (7.62 cm) long by 2 inches (5.08 cm) thick. The filled basket was attached to an anchor and allowed to float about 8 inches (20.32 cm) off the bottom of the stream. The baskets were first put in place in May and were then sampled at approximately 1-month intervals through October, for a total of five collections.

Collection procedure began by recovering the sampler with a dip net which was modified to fit over the anchor cable allowing the basket to be totally contained within the mesh. The basket, and any organisms in the net, were then sealed in a large plastic bag and another sampler was placed on the site. In cases where the sampler was lost, Surber samples were taken to fill the data gap. Because of repeated vandalism, the Surber net was used exclusively at stations EF-3 and EF-5 for the last three sampling periods.

Upon arrival at the field lab, the contents of the basket and the plastic bag were emptied into a bucket of water. Each bark chip was brushed with a stiff-bristle brush to remove all organisms. After all the chips had been removed, the contents of the bucket were poured onto a No. 30 (0.595-mm openings) sieve. The invertebrates were handpicked from among the debris and vegetation and preserved in a 70-percent ethanol solution.

Data collected from 1971 through 1973 were also available for use in this study. The 1971 and 1972 collections were obtained with a Surber net, while the 1973 collections were obtained with basket-type artificial substrate samplers. The artificial substrate samplers differed from those described above in that:

1. The commercial barbeque baskets were flat, rectangular boxes.

2. The filler material was a mixture of porcelain balls and rounded rocks about 3 inches (7.62 cm) in diameter.

3. The baskets rested directly on the bed of the stream.

The collection periods were irregular, with the baskets being sampled in June, July, and September 1973.

Collection procedure was essentially the same as described above, except that the samplers were recovered without the use of a net.

Fish.—Fish samples were collected with the aid of Colorado Division of Wildlife personnel on September 18, 1974, at or near stations EF-3, EF-5, AR-3, AR-4, AR—5, and AR-7. A 100-yard section of stream was sampled for total number of fish except at AR-4 where about a 400-yard stream section was sampled. A 115-volt Coffelt Model BP-2 backpack and 115/230-volt stationary electrofishing units were employed at each station. Shocking was done upstream, fish being collected with dip nets and placed in a portable live box. All fish were measured and recorded by species. A selection from each station was preserved for further analysis; the remainder were marked by fin clipping for future studies by the Division of Wildlife and returned to the river. Fish were preserved in 15 percent reagent grade formalin solution. After 5 days in formalin solution, the fish were washed thoroughly and placed in a 70-percent ethyl alcohol solution. Some of the formalin solution from each sample was saved for chemical comparison of heavy metal concentration.

Fish were dissected soon after preservation in alcohol. Before dissection, each fish's standard length, sex, and species were recorded, and the fish was coded by placing a tag in the mouth. Both sides of the fish were removed with the skin. These fillets, plus skin, and a coded tag were then placed in foil and frozen until heavy metal analysis could be done.

Methods of Analysis

Water.—The exact procedures used for the chemical examination of water are described in APHA Standard Methods, 13th edition (1971). The following is a summary of methods:

Specific conductance—Conductance cell and a wheatstone bridge
Total dissolved solids—Filter through a 0.45 μm filter and evaporate at 105° C
Calcium and magnesium—EDTA Titrimetric methods
Sodium and potassium—Flame photometric method
Hydrogen-ion concentration (pH) and alkalinity—Potentiometric titration
Sulfate—Gravimetric method
Chloride—Argentometric method
Nitrate—Phenoldisulfonic acid method
Trace metals—Perkin-Elmer Model 303 atomic absorption spectrophotometer was used to analyze for Cu, Zn, Mn (detection limits, d.l. = 0.05 p/m), Fe (d.l. = 0.1 p/m), Pb (d.l. = 0.2 p/m), Mo (d.l. = 0.3 p/m)

Sediment.—The bottom sediments, which were collected in plastic bags, were air dried and screened through a 1.65-mm screen. Twenty grams were dissolved in 25 percent nitric acid, and analyzed using atomic absorption spectrophotometry as described under water chemistry.

Fish.—Five grams of filleted fish sample were heated at 650° C for 4 hours, dissolved in 25 percent nitric acid, and analyzed using atomic absorption spectrophotometry as described under water chemistry. Fish samples spiked with the trace metals averaged 96 percent recovery.

Invertebrates.—Preserved macroinvertebrate collections were sent to D. L. Galat, then at the Colorado Cooperative Fisheries Unit at Colorado State University, Fort Collins, Colo. The organisms were identified to the genus level, the number of individuals per genus were determined, and three diversity indices were calculated for each collection: $\bar{d}$ (mean diversity), e (equitability) and TCI′ (trophic condition). A computer program at Colorado State University was used to calculate the indices. Equations and methods basic to the calculations are discussed below.

Mean diversity was calculated from the equation (Wilhm & Dorris, 1968):

$$\bar{d} = \sum_{i=1}^{s} \frac{n_i}{N} \log_2 \frac{n_i}{N} \qquad [1]$$

where: s = total number of genera in the sample
n_i = number of organisms in the i^{th} genus
N = total number of organisms in the sample.

The resultant $\bar{d}$ is a dimensionless number, theoretically in the range from zero to any positive number, but in practice seldom greater than 10 (Dills & Rogers, 1974).

Equitability, e, was determined from the following relationship (Lloyd & Ghelardi, 1964):

$$e = \frac{s'}{s} \qquad [2]$$

where: s = total number of genera in the sample
s′ = number of genera expected from a community that conforms to the MacArthur "broken-stick" model of species distribution (tabulated values).

The calculated e is a dimensionless number, commonly ranging from 0 to 1. In samples containing only a few individuals with several genera represented, however, the value of e will be greater than one (Weber, 1973).

The final diversity index determined for these collections was trophic condition. First, the individual organisms were grouped into one of three categories, according to their tolerance of organic wastes and low dissolved oxygen levels (Weber, 1973):

Class I—Tolerant
Class II—Facultative (adaptable)
Class III—Intolerant

Then, trophic condition was calculated from the equation:

$$TCI' = \frac{N_1}{N}(2.0) + \frac{N_2}{N}(1.0) = \frac{N_3}{N}(0.0) \qquad [3]$$

where: N = total number of organisms in the sample
N_1 = number of organisms in Class I
N_2 = number of organisms in Class II
N_3 = number of organisms in Class III

TCI′ is dimensionless and ranges in value from 0 to 2.

The 1971-73 collections were identified and counted by D. A. Hoffman, formerly of the Bureau of Reclamation, who also used these data to compute mean diversity indices, equation (1).

The dry weight of the invertebrate samples was determined at 105° C. The total sample was heated at 650° C for 4 hours, dissolved in 25 percent nitric acid, and analyzed using atomic absorption spectrophotometry as described under water chemistry.

RESULTS AND DISCUSSION

Physical And Chemical

Field measurements.—Figure 22 presents Arkansas River and Lake Fork water temperatures recorded by thermographs from May through September 1973. Observe the difference between the extreme diurnal temperature variations at the Arkansas River stations and the relatively small variations at the Lake Fork station, which represents the outflow from the hypolimnion of Turquoise Lake.

Daytime temperatures at station AR-1 for the month of August 1973, are somewhat erratic, which may have been caused by the exposure of part of the temperature probe to air when stream levels dropped. This situation was discovered and remedied in late August. While these graphs indicate warming between stations AR-1 and AR-7 (downstream), the situation around station AR-5 is rather complex. It would seem that the temperatures here are heavily influenced by the inflow of Lake Fork.

Figures 23 through 27 present results of physical and chemical measurements taken April through November 1974. All flows on these figures are for the date on which the collection was made. Figures 23 through 25 present data by station while figures 26 and 27 are by

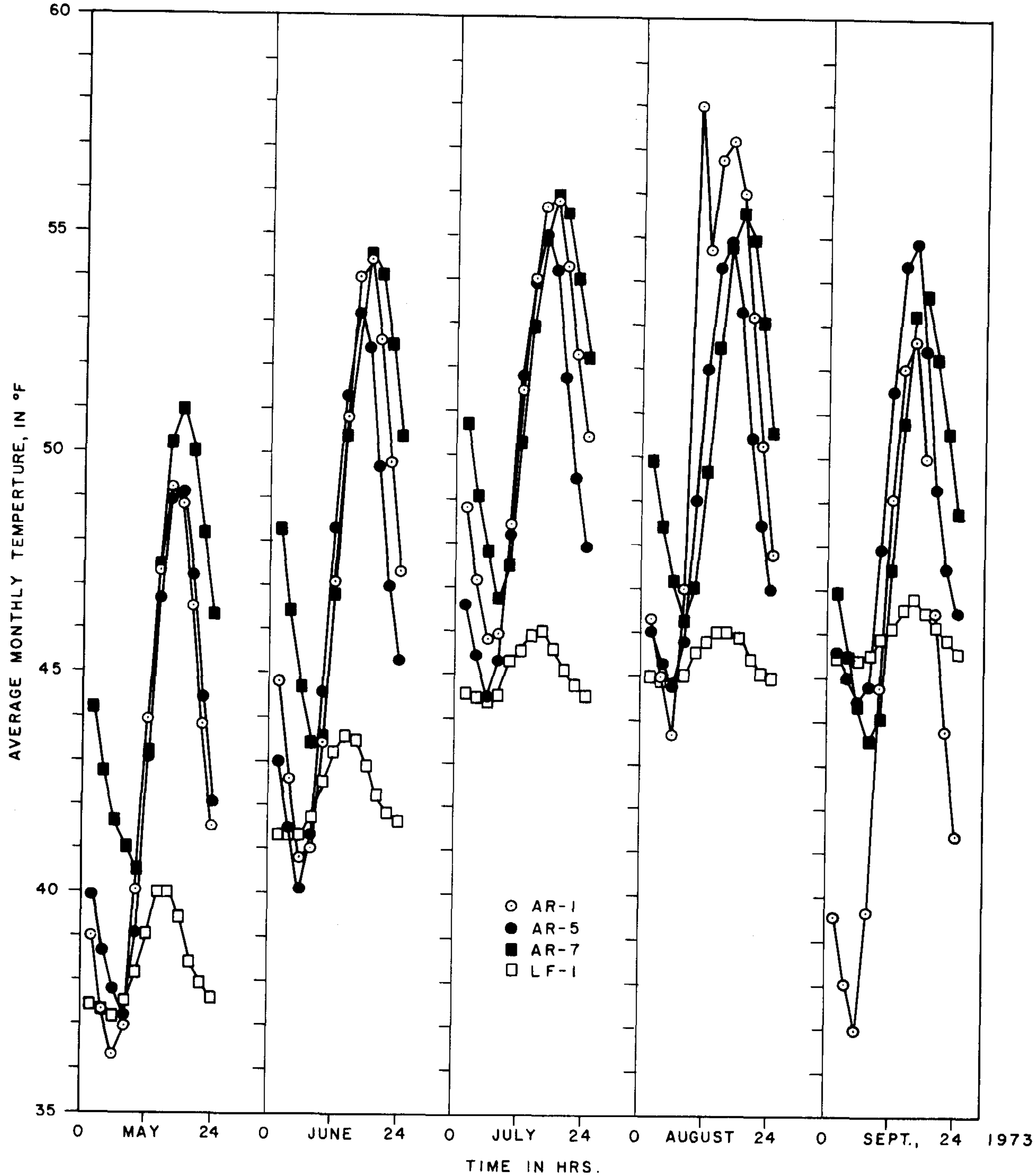


Figure 22. Upper Arkansas River and Lake Fork water temperatures, 1973.

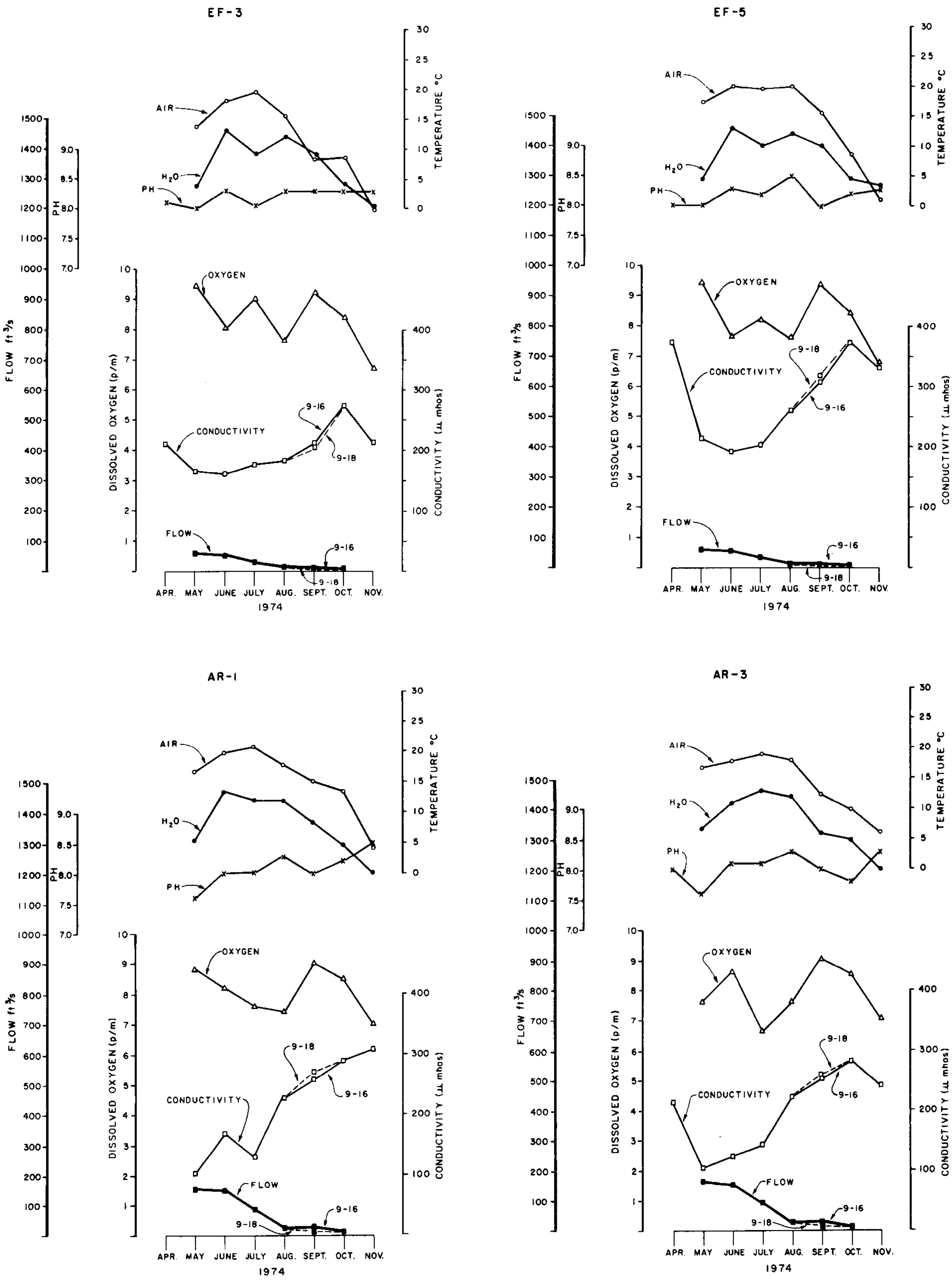


Figure 23. Results of physical and chemical measurements at stations EF-3, EF-5, AR-1, and AR-3—1974.

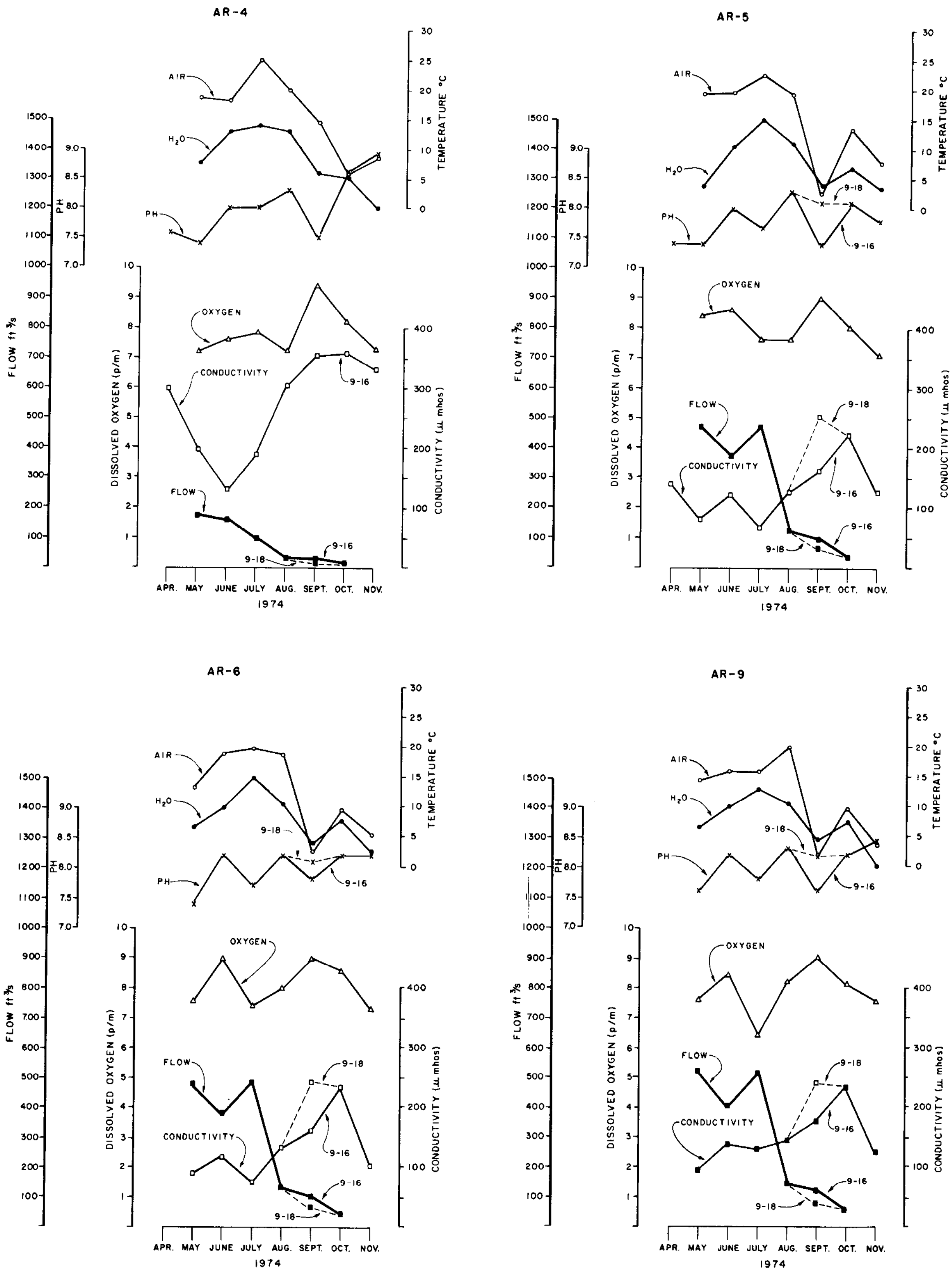


Figure 24. Results of physical and chemical measurements at stations AR-4, AR-5, AR-6, and AR-9—1974.

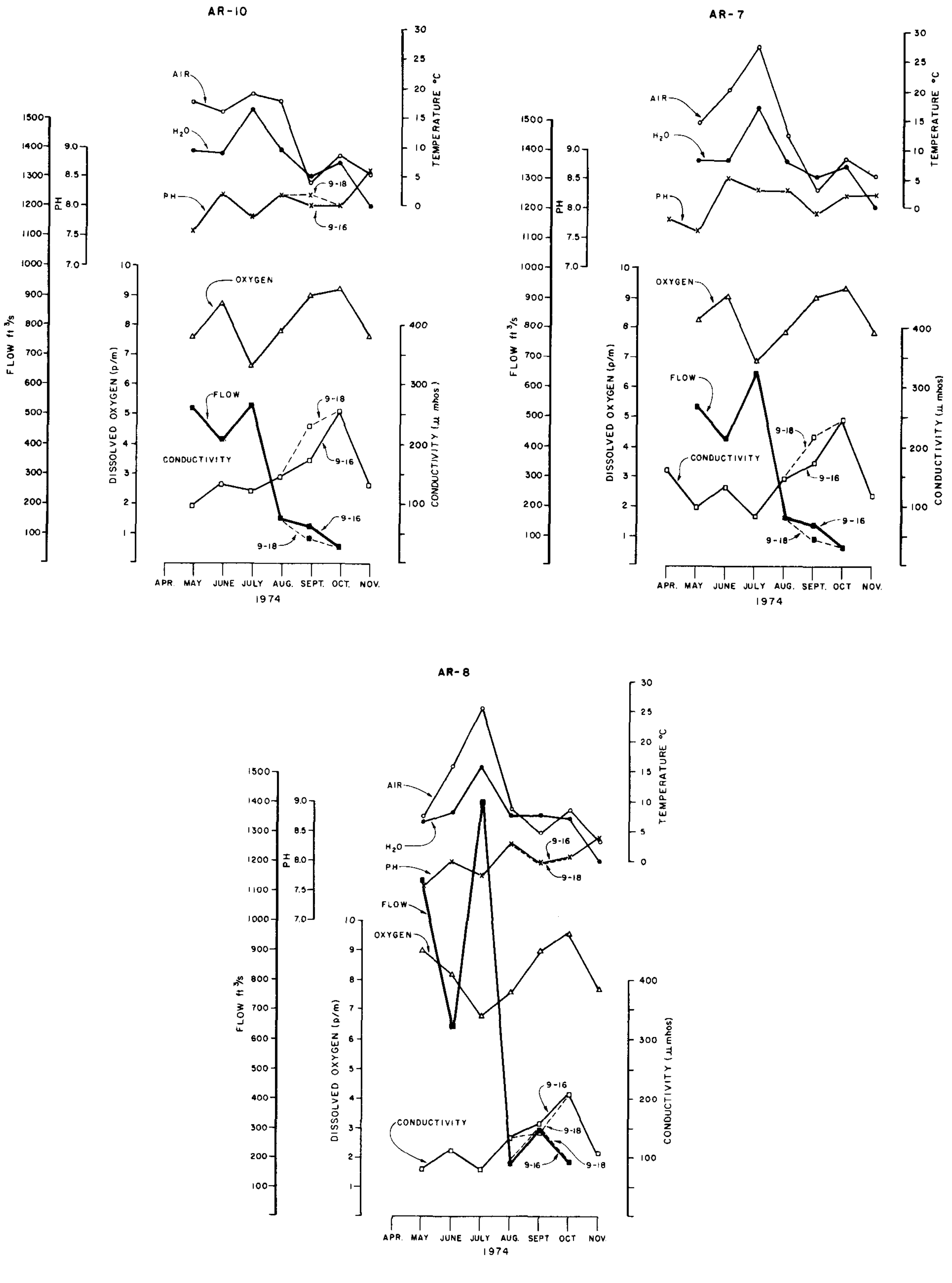


Figure 25. Results of physical and chemical measurements at stations AR-10, AR-7, and AR-8—1974.

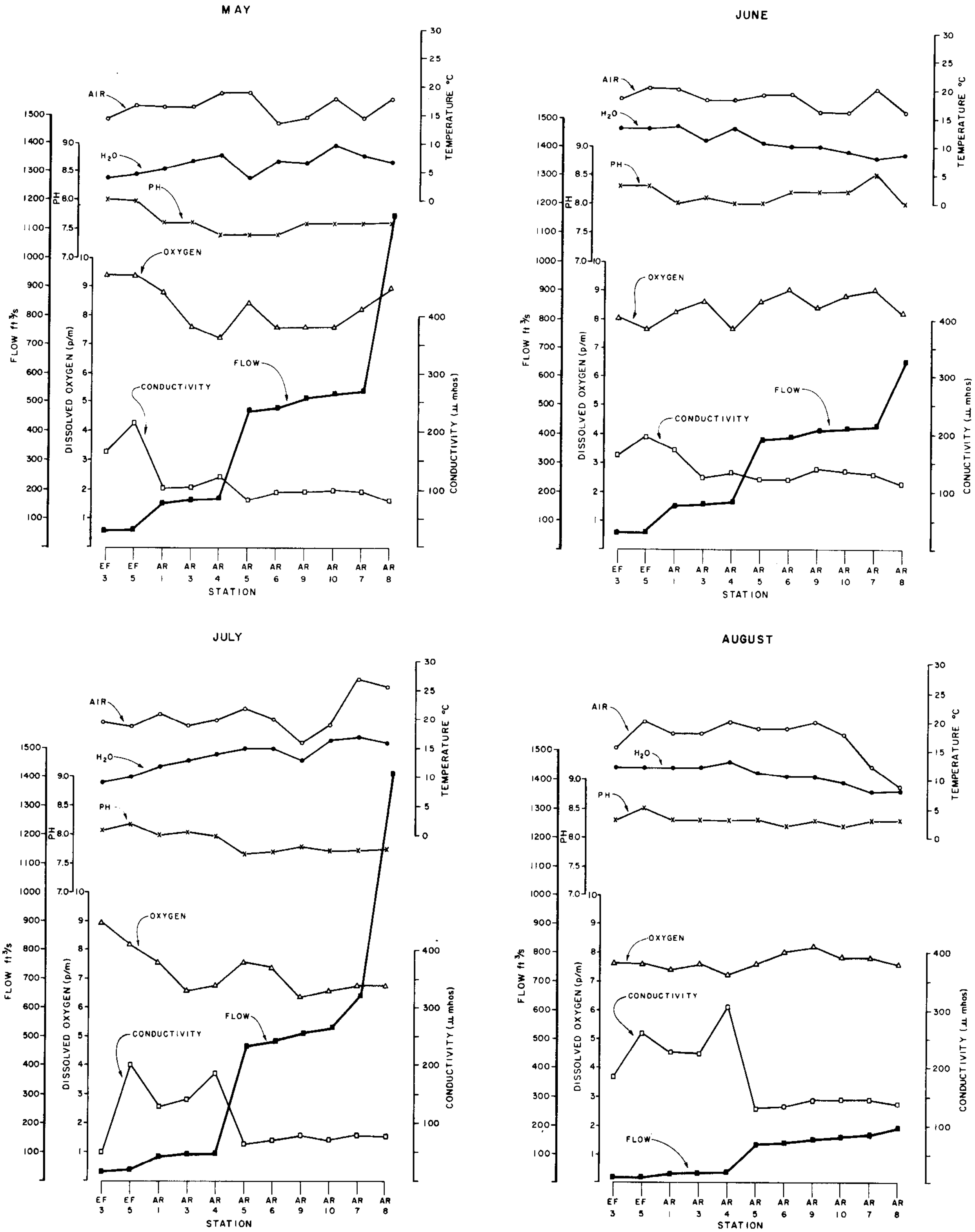


Figure 26. Results of physical and chemical measurements in May, June, July, and August—1974.

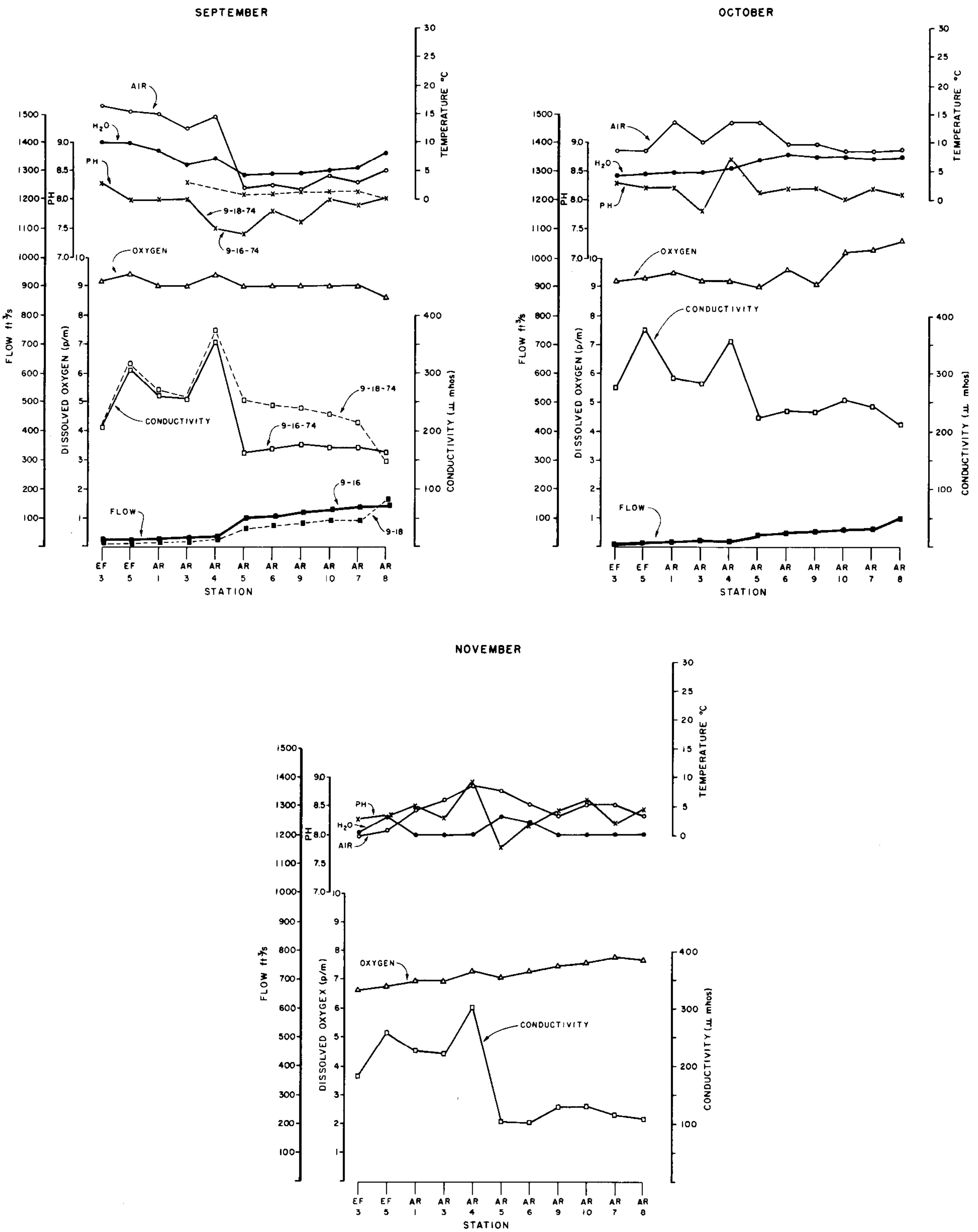


Figure 27. Results of physical and chemical measurements in September, October, and November—1974.

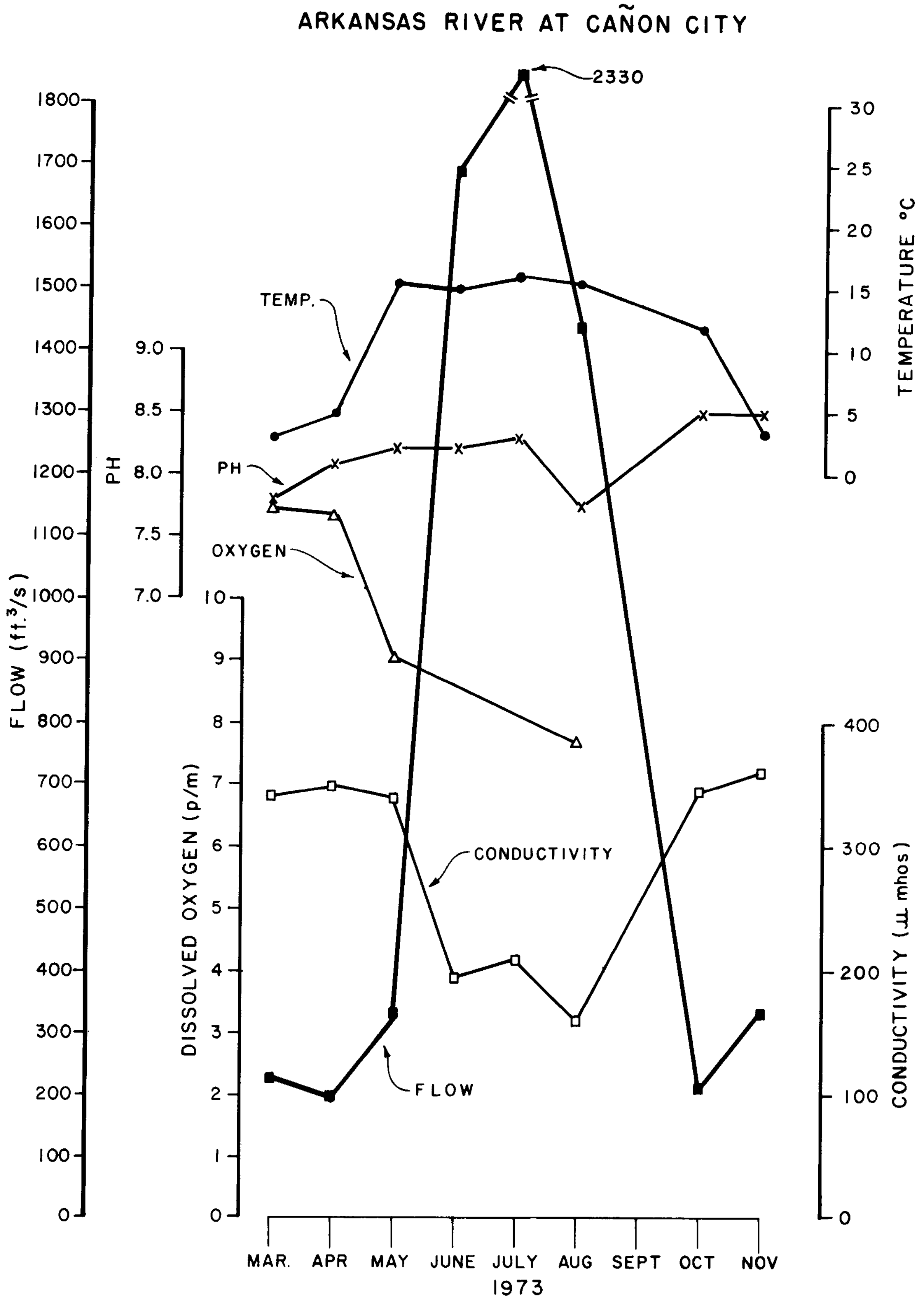


Figure 28. Results of physical measurements at the USGS Gage at Cañon City, Colo.—1973.

sampling date. Figure 28 presents data collected by USGS at the streamflow gage at Cañon City, Colo., in 1973. Data are presented by month and again by station to allow easier comparison of river conditions in the upper Arkansas with those farther downstream. In addition, trends resulting from both seasonal and geographical influences are more obvious. In each instance the influence of ambient air temperature on water is apparent. Only in some cases later in the season does the air temperature fall below that of the water. Data indicate that the highest average water temperature occurs sometime from the latter part of July through the first half of August. There is a general rise in pH as the season progresses, probably reflecting an increase in alkalinity of the water. Progressing downstream, there is no significant change in pH during May, June, July, or August. During September there is a drop in pH of the Arkansas River below the inflow of Leadville Drain and a further drop below the inflow of California Gulch. This drop may reflect the contribution of the relatively more acidic drainage from Leadville Drain and California Gulch at the same time that flows of the Arkansas River are relatively low. Therefore, these two inflows have more of an influence on the pH of the river than they had earlier in the season. However, in October and November, pH and conductivity parallel each other as would be expected; that is, as conductivity rises so does pH.

Dissolved oxygen concentrations were always sufficient to support aquatic life. Data in figures 26 and 27 indicate dissolved oxygen changing quite abruptly, especially from month to month. However, these fluctuations are biologically insignificant. The lowest dissolved oxygen concentration recorded was 6.4 p/m.

Water with dissolved oxygen concentrations over about 6 p/m is supersaturated. These fluctuations are caused by the following or a combination of the following factors:

1. Water at colder temperatures holds more dissolved oxygen; thus, as data in figures 23 through 28 indicate, as temperature falls dissolved oxygen concentrations increase.

2. As light intensity increases diurnally, aquatic plant activity increases producing more dissolved oxygen.

3. As the amounts of available light increase seasonally (i.e., longer day length and more direct rays from the sun), photosynthesis also is increased as in 2.

4. As turbulence increases, as a result of increased flows, so do dissolved oxygen concentrations. Therefore, in some areas (i.e., station AR-8 below the inflow of Lake Creek) dissolved oxygen concentrations were higher when releases out of Twin Lakes were high.

The conductivity curve presented in figures 23 through 25 is similar at each station. Conductivity levels were lowest in May, June, and July. This is the same time that runoff is highest. Conductivity levels are generally at their highest in October, resulting from reduced dilution of the steady input of dissolved salts. In September, two water samples each were collected at selected stations; one on September 16 and another on September 18, which followed a reduction of the flows from Turquoise Reservoir by about 30 ft^3/s. Flows were lowered to permit fish sampling of the river. Broken lines in figures 23 through 27 connect data collected on September 18. Conductivities ranged from a low of 66 μmho on July 18, 1974, at AR-5 to a high of 355 μmho on September 16, 1974, at AR-4. It is significant that the lowest conductivity of the year was recorded when flow from Turquoise Reservoir was highest. This indicates the extreme freshening effect this flow has on the river. Increases in conductivity also occur seasonally because of increased evaporation. Figures 26 and 27 present data which show that from above Leadville Drain to below Lake Creek, the conductivity decreases as the water moves away from the influence of Leadville Drain and California Gulch. Figure 28 shows conductivity levels to be higher at Cañon City than they were at the confluence of Lake Creek, which is to be expected because of evaporation, erosion, and tributary influence. The effects of increased flows on conductivity are especially dramatic in July; however, the general pattern occurs each month. There is a rise in conductivity between EF-3 and EF-5 reflecting the influence of Leadville Drain. Conductivity rises at AR-4 because of the inflow of California Gulch which contains a high level of TDS (total dissolved solids). Conductivity drops significantly at AR-5, because of the relatively fresh flows of Lake Fork. There is then a general increase in conductivity between AR-5 and AR-7 caused by diffuse pollution sources on the west side of the Arkansas River. Finally, the freshening flows of Lake Creek are reflected in lower conductivity levels at AR-8. The pattern just described for conductivity will again be apparent when heavy metals are discussed. The relationship between flow and conductivity is ever apparent in figures 23 through 27. A correlation of −0.89 plus or minus 0.05 was calculated between flow and conductivity on data collected at all stations from May through October 1974. This indicates a very strong negative correlation between flow and conductivity. Thus, at any station, as flow decreases, conductivity increases, or vice versa. This relationship has important implications for the area immediately below the point of inflow of Lake Fork and Halfmoon Creek. The highest conductivities were found at AR-4, just above this point, while at AR-5, immediately below the confluence, conductivities were significantly decreased. It is apparent from the inverse correlation between conductivity and flow that improvement in quality at AR-5 is due largely to the inflow from Lake Fork and Halfmoon Creek. A diminution of flow at AR-5 by diversion of these streams would be expected to increase conductivity to levels approximating those at AR-4.

Table 1, appendix B, presents streamflow data from May through October 1974. Figure 29 shows the mean flow at each station for this time period. Note the heavy contributions of Lake Fork and Lake Creek. When the Fryingpan-Arkansas Project is fully implemented as presently envisioned, these contributions can be expected to be greatly decreased.

The following is a direct quote from a memorandum from Lower Missouri Regional Director James M. Ingles to Research Division Chief Howard J. Cohan dated November 19, 1974, regarding effect of the Mt. Elbert conduit on the streamflow of the upper reaches of the Arkansas River.

"Operation of Mt. Elbert Conduit will have no effect on the streamflow of the Arkansas River above the confluence of that stream with Lake Fork, no effect on heavy metals study station AR-4 and all stations upstream.

"The flow of Halfmoon Creek will be reduced by 150 c.f.s. [sic] or to a minimum of 16 c.f.s. During the years of record, Halfmoon Creek flow has averaged 29.0 c.f.s. in Water Year 1971, a near average year on Halfmoon Creek, the mean monthly streamflows were as follows: October, 17 c.f.s.; November, 10 c.f.s.; December, 7 c.f.s.; January, 4 c.f.s.; February, 3 c.f.s.;March, 3 c.f.s.; April, 4 c.f.s.; May, 30 c.f.s.; June, 142 c.f.s.; July, 81 c.f.s.; August, 31 c.f.s.; and September, 21 c.f.s.

"It is difficult to establish a standard or average year for the flow of the Lake Fork below Sugar Loaf Reservoir. As Lake Fork was regulated by Turquoise Lake and as transmountain imports are carried in the channel of Lake Fork, it is difficult to determine which condition represents historic condition. Busk-Ivanhoe, with rights up to 180

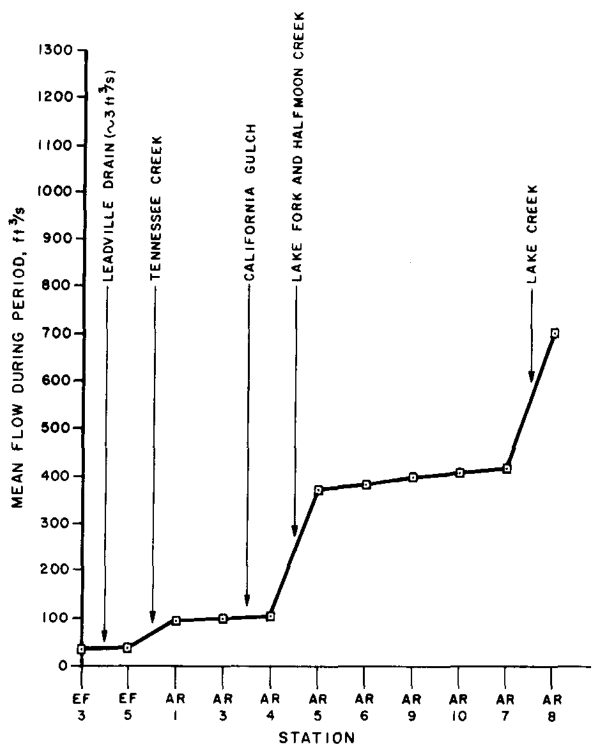


Figure 29. Seasonal mean flow for the upper Arkansas River, Colorado—1974.

c.f.s., began importing Ivanhoe Creek water into Lake Fork in June 1925. The Homestake Project began importing Homestake Creek water into Lake Fork in April 1968. Homestake has been holding their imports to 300 c.f.s. or below. The Fryingpan-Arkansas Project's Boustead Tunnel began importing Fryingpan River water from a partially complete collection system in May of 1972. When the collection system is complete, the Boustead Tunnel will be capable of importing 945 c.f.s. to date. However, the maximum imports have been under 600 c.f.s.

"The CF&I Steel Company, when they controlled Turquoise Lake, could store all the native flow of Lake Fork during the winter months. Under project conditions, a minimum of 3 c.f.s. will be maintained below Sugar Loaf Dam. Also, nearly 7 c.f.s. will be delivered to the Leadville National Fish Hatchery. As this is a nonconsumptive use, most of this water will find its way back into Lake Fork, helping to sustain a live flow.

"Under project condition, Lake Fork and Halfmoon water will be diverted around Granite, and heavy metals study section [sic] AR-8, in Otero Canal. However, a minimum flow of 66 c.f.s. will be maintained at Granite."

Water chemistry.—Water chemistry data from Bureau of Reclamation surveys of 1969, 1971, 1972, 1973, and 1974, are in appendix A . Also included are data collected by the USGS from the Arkansas River at Granite, Colo., in 1967 and 1968, and the Arkansas River at Cañon City, Colo., in 1972 and 1973.

The cation-anion properties of the water are similar to those of most high mountain streams in Colorado. The concentration of any particular element or compound increases below polluted inflows and decreases below relatively nonpolluted inflows. Calcium concentrations in the Arkansas are mostly below 30 p/m which is the acceptable level for drinking (McKee & Wolf, 1963). Calcium in water reduces the toxicity of heavy metals to fish. For example, mature fish have been killed by 0.1 p/m lead in water containing only 1 p/m calcium, but have not been harmed by the same amount of lead in water containing 50 p/m calcium (McKee & Wolf, 1963). A concentration of 50 p/m calcium has cancelled the toxic effect upon some fish of 2 p/m zinc and 10 p/m lead (Jones, 1938).

Magnesium concentrations of the Arkansas River do not exceed 20 p/m and are mostly below 10 p/m. Limits for domestic water supplies are always above 100 p/m. McKee and Wolf (1963) cite a report that among United States waters supporting a good fish fauna, ordinarily 5 percent have less than 3.5 p/m magnesium, 50 percent have less than 7 p/m, and 94 percent have less than 14 p/m. To be toxic to aquatic life, magnesium in such compound forms as magnesium chloride, nitrate, or sulfate, must be in concentrations of well over 500 p/m magnesium.

Sodium is a very active metal that does not occur free in nature. The toxicity of sodium salts depends largely on the anion involved, the chromate being exceedingly toxic and the sulfate least so. Concentrations of sodium in Arkansas River water are always below 6 p/m. Of the United States waters supporting a good fish fauna, ordinarily the concentration of sodium plus potassium is less than 6 p/m in about 5 percent, less than 10 p/m in about 50 percent, and less than 85 p/m in about 95 percent (Hart *et al.*, 1945).

Potassium, also a very active metal, reacts vigorously with oxygen and water. It is, therefore, not found free in nature, but only in ionized or molecular form. Potassium resembles sodium in many of its properties. Potassium concentrations in Arkansas River water were mostly below 4 p/m, which is a very acceptable level for both domestic supplies and aquatic life.

Carbonate was rarely found in the Arkansas River. When it was found, the levels were very low, less than 7 p/m. The concentrations of carbonates in natural and polluted waters is a function of temperature, pH, cations, and other dissolved salts. In general, it may be expected that carbonates, in themselves, are not detrimental to fish life. However, the buffering action of carbonates and their effect upon pH may contribute to the toxicity of high alkalinity. The amounts found in Arkansas River water are far below that required to be harmful to fish.

Like carbonates, the concentration of bicarbonates in natural and polluted waters is a function of temperature, pH, and concentrations of other dissolved solids. Bicarbonates may reach the water from many natural sources, including absorption of carbon dioxide from the air and the decomposition of organic matter, or they may be discharged as a pollutant. Other than the fact that excessive bicarbonates add to the salinity and total solid content of water, and through the complex operations of the carbonate equilibria, tend to form carbonates and scale at high temperature, bicarbonates in water are seldom considered to be detrimental. Concentrations of bicarbonates in Arkansas River water above the confluence of Lake Creek never exceed 130 p/m. The 10-year weighted average analyses of Colorado River water, according to Kelley (1937), show 172 p/m bicarbonate. In United States waters that support a good fish fauna, 5 percent of such waters have less than 40 p/m bicarbonate, 50 percent have less than 90 p/m, and 95 percent have less than 180 p/m (Hart *et al.*, 1945).

Sulfates occur naturally in waters, particularly in the western United States, as a result of leaching from gypsum and other common minerals. In the Arkansas River, sulfate concentrations were almost always below 110 p/m. In California Gulch and Leadville Drain they were always notably high, averaging about 560 p/m for California Gulch and 300 p/m for Leadville Drain. In United States waters that support good game fish, 5 percent of the waters contain less than 11 p/m of sulfates, 50 percent less than 32 p/m, and 95 percent less than 90 p/m (Hart *et al.*, 1945). On the basis of information gleaned from the literature, it appears that concentrations of under 200 p/m sulfate will not be detrimental for domestic, irrigation, or stock watering uses. The USPHS (United States Public Health Service) Drinking Water Standards of 1962 recommend that sulfates do not exceed 250 p/m.

Concentrations of chloride in Arkansas River water above the confluence of Lake Creek was always below 8 p/m and mostly below 4 p/m. These concentrations are very low and pose no threat to aquatic life. The USPHS Drinking Water Standards of 1962 recommend that chlorides do not exceed 250 p/m. McKee and Wolf

(1963) cite data indicating that among United States waters supporting a good fish fauna, ordinarily the concentration of chlorides is below 3 p/m in 5 percent, below 9 p/m in 50 percent, and below 170 p/m in 95 percent of such waters. Adams (1940) reported 400 p/m of chloride harmful to trout.

Nitrates are the end product of the aerobic stabilization of organic nitrogen. They occur in polluted waters that have undergone self-purification or aerobic treatment processes. Nitrates are seldom abundant in natural surface waters. Photosynthetic action is constantly utilizing nitrates and converting them to organic nitrogen in plants. The USPHS Drinking Water Standards of 1962 recommended a limit of 45 p/m nitrates. High nitrate concentrations in water stimulate the growth of plankton and aquatic plants. By increasing plankton growth and the development of fish food organisms, nitrates directly benefit increased fish production. Nitrate was not regularly found at any of the sampling stations; it occured most commonly at AR-10 which is below the runoff from pastureland on the west side of the river and the drainage from the Mt. Massive Trout Club ponds on the east. The highest level found at this station was 1.24 p/m. The maximum amount of nitrate found in this area of river was 2.48 p/m at station EF-5 which is below the outflow of Leadville Drain and the sewage lagoons from a trailer park. The maximum amount of nitrate found in the Arkansas River below the inflow of California Gulch was 1.83 p/m; the maximum amount found in California Gulch water was 13.6 p/m. All values are, therefore, well below the USPHS Drinking Water Standards of 1962. McKee and Wolf (1963) report references to the effect that among United States waters supporting a good fish life, ordinarily 5 percent have less than 0.2 p/m, 50 percent have less than 0.9 p/m, and 95 percent have less than 4.2 p/m nitrates.

Figures 30 through 36, table 2, and appendix A present data on zinc, copper, lead, manganese, and iron concentrations of the upper Arkansas River, Colorado, from just above Leadville to Cañon City. Flows for the dates on which the samples were collected are also plotted in figures 30, 31, 32, 34, and 35. Figures 30 through 32 contain plotted heavy metal vs. collection date data from the 1974 field season. Figure 33 contains plotted data collected by USGS at their streamflow gages on the Arkansas River at Granite and Cañon City in 1968 and 1973, respectively. Figures 34 and 35 contain plotted heavy metal vs. sampling station data from the 1974 field season. Figure 36 presents averages of heavy metal concentrations vs. sampling station for the period April-November 1974. Seasonal variation in iron, zinc, copper, lead, and manganese concentrations at each of the stations sampled is depicted in figures 30 through 32. Flow is a major factor in determining the concentrations of heavy metals at each station. In September, samples were collected before and after the flow was reduced by about 30 ft^3/s at AR-5, AR-6, AR-9, AR-10, AR-7, and AR-8.

The downstream and seasonal variation in heavy metal concentrations is apparent for some elements, especially zinc and manganese. Moran and Weltz (1974) reported seasonal variations in metal concentrations of California Gulch, the main contributor. The September plot in figure 35 also presents these data. There was no detectable amount of lead in California Gulch in September; thus, it does not show up downstream. However, it would be expected that when the amounts of lead or copper are high in California Gulch, concentrations in the river below would also be relatively high.

Concentrations of iron ranged from less than 0.1 p/m at EF-3, AR-1, and AR-3 in October to about 5 p/m at AR-4 in November 1974. The average concentration of iron in water collected from the upper Arkansas River during the period of this study ranged from 0.28 p/m at AR-1 to 2.62 p/m at AR-4 (fig. 36 and table 2). The average amount of iron in Leadville Drain and California Gulch water was 1.80 and 25.87 p/m, respectively. The 1962 Drinking Water Standards of the USPHS included a recommended limit of 0.3 p/m iron. Thus, water from only one station would, on the average, pass USPHS standards. Waters that support good fish fauna in the United States, according to Hart *et al.*, (1945), have concentrations of iron of 0.0 p/m in 5 percent, 0.3 p/m in 50 percent, and 0.7 p/m in 95 percent of the waters. Excessive concentrations of iron can kill fish by coating their gills with iron oxide or hydroxide precipitates. A concentration of 0.2 p/m iron is lethal to some fish while others will withstand 50 p/m. Sykora (1972) found that growth rates in trout were reduced because visibility was impaired by suspended iron, preventing fish from feeding.

Concentrations of zinc ranged from less than 0.05 p/m at EF-3 in April, June, July, August, and October 1974, to 4.6 p/m at AR-4 in November 1974. The average concentration of zinc over the period sampled ranged from less than 0.05 p/m at EF-3 to 2.83 p/m at AR-4 (fig. 36 and table 2). The average concentrations were 4.00 and 32.47 p/m for Leadville Drain and California Gulch, respectively. The 1962 Drinking Water Standards of the USPHS included a recommended limit of 5 p/m zinc. This value is chosen because it is the taste threshold. It takes very high levels to cause injury to man. It is towards fish and

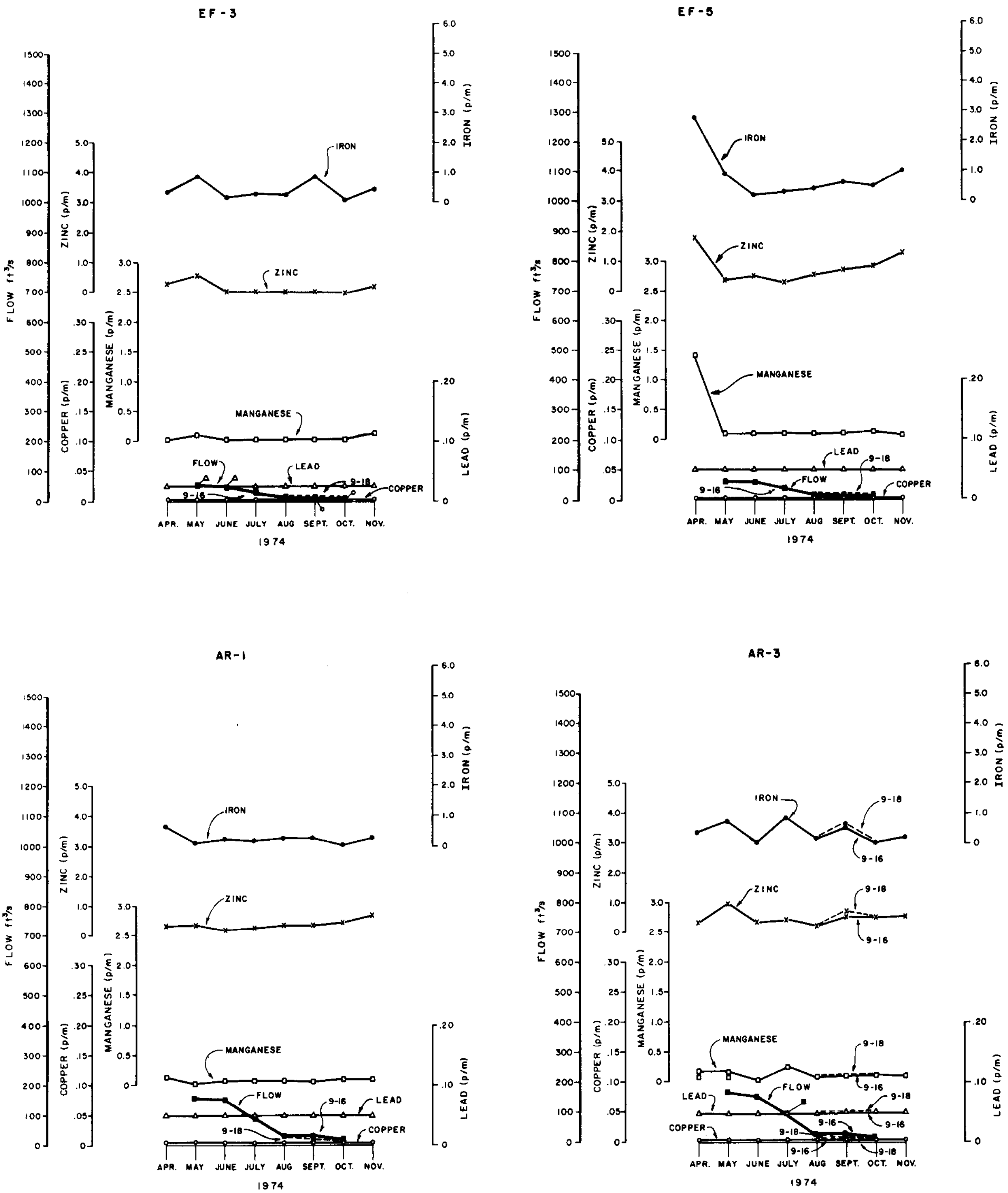


Figure 30. Heavy metal concentration vs. flow at sampling stations EF-3, EF-5, AR-1, and AR-3—1974.

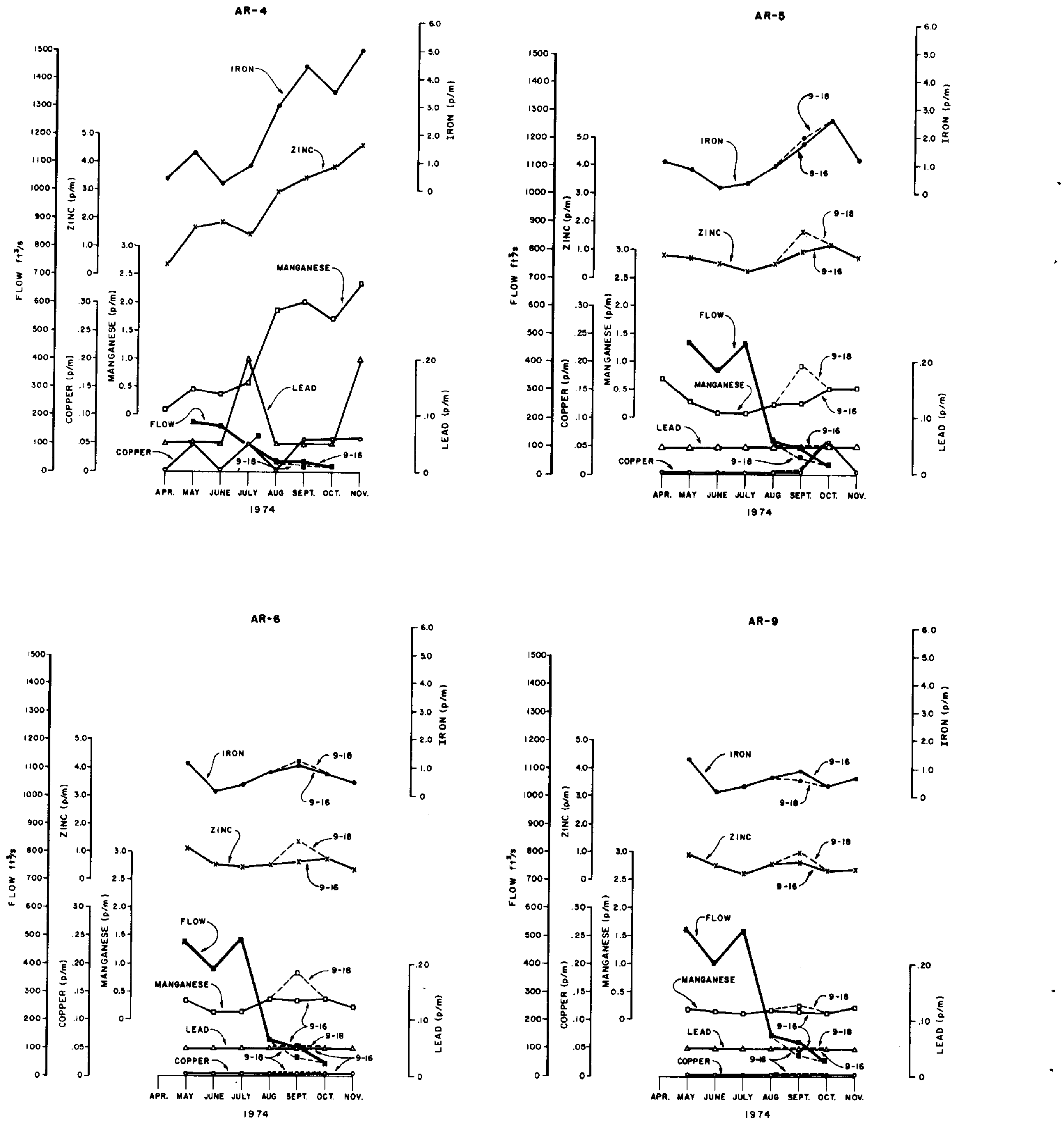


Figure 31. Heavy metal concentration vs. flow at sampling stations AR-4, AR-5, AR-6, and AR-9—1974.

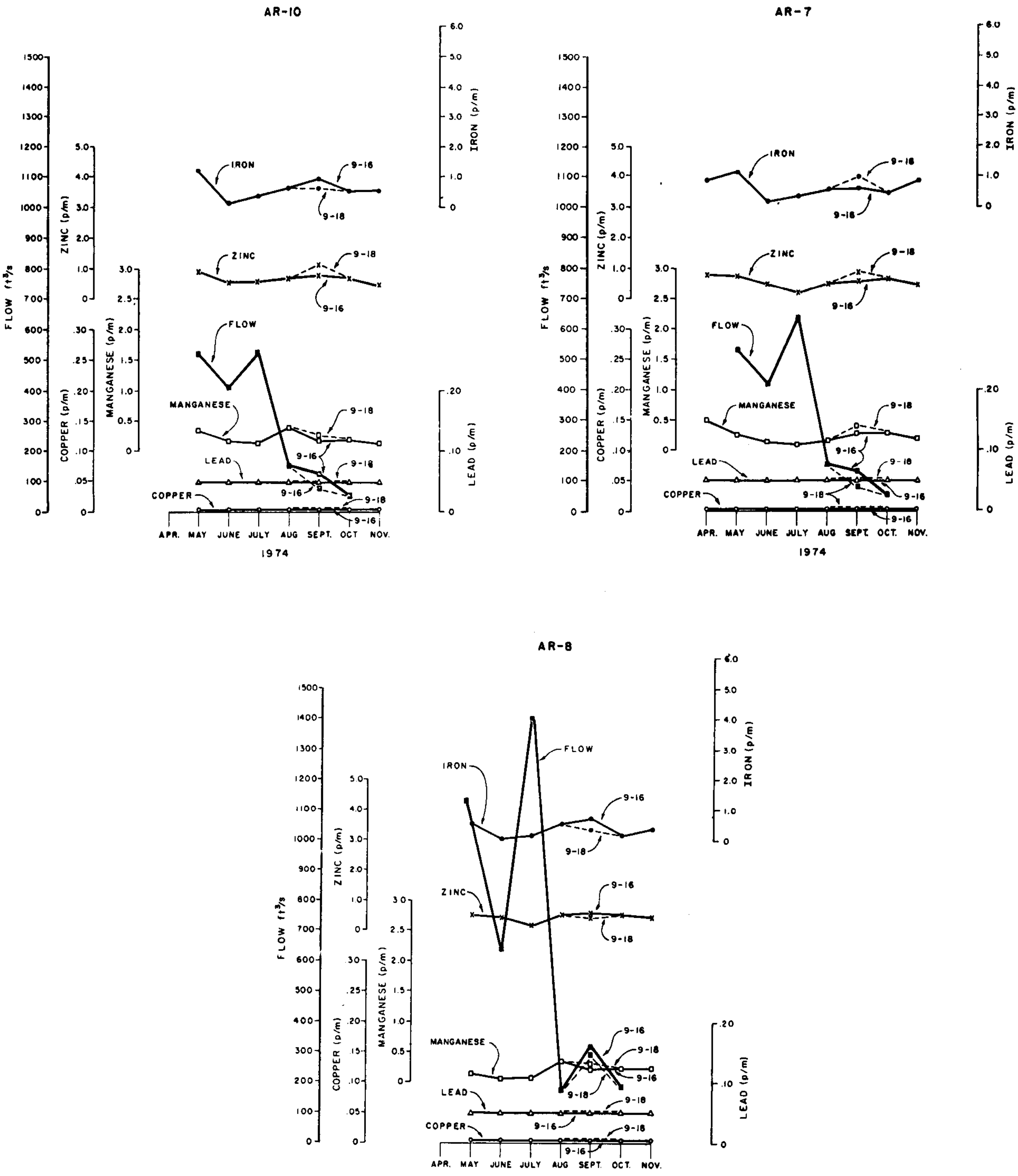


Figure 32. Heavy metal concentration vs. flow at sampling stations AR-10, AR-7, and AR-8—1974.

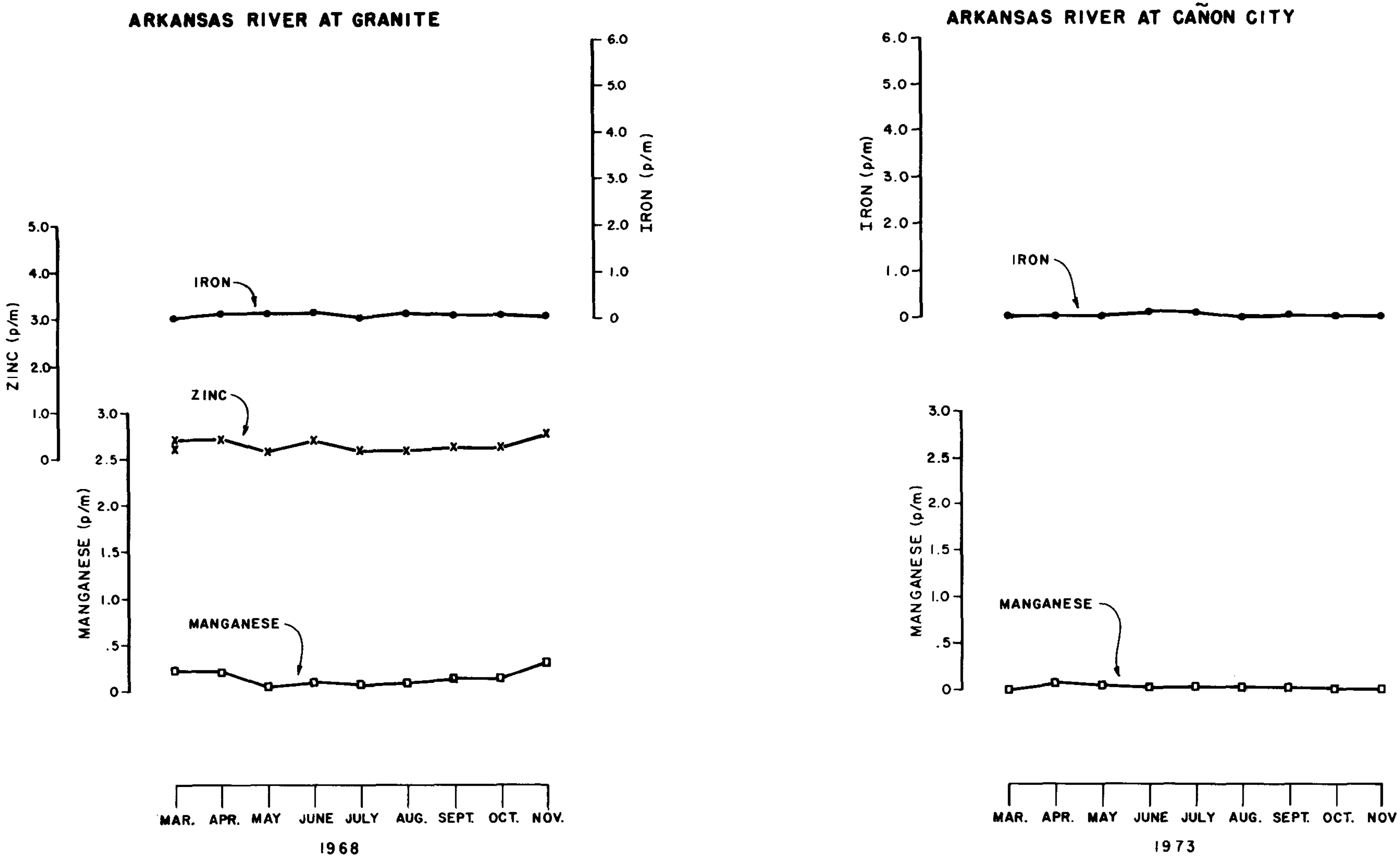


Figure 33. Heavy metal concentrations at Granite and Cañon City—1968 and 1973, respectively.

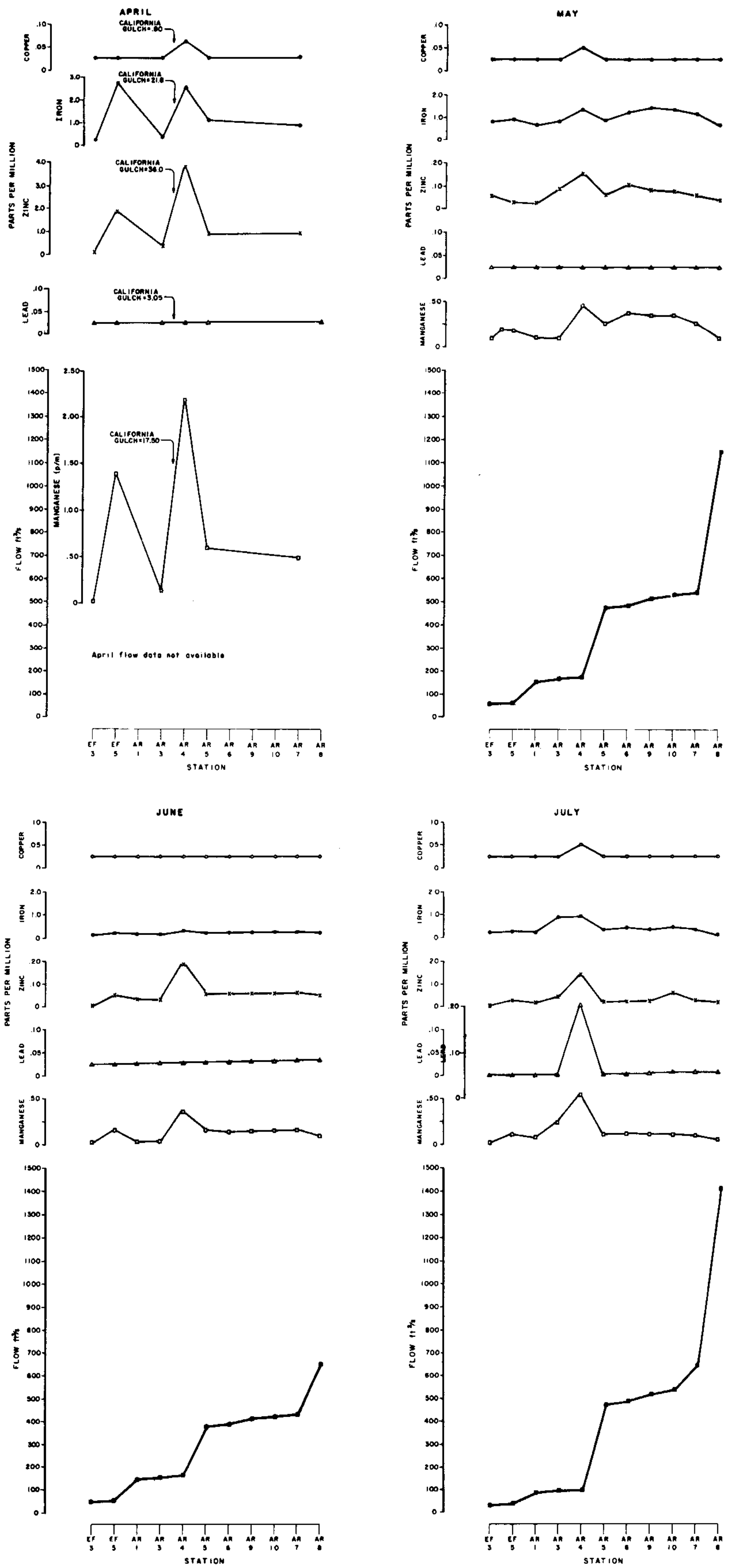


Figure 34. Heavy metal concentrations and flow April, May, June, and July—1974.

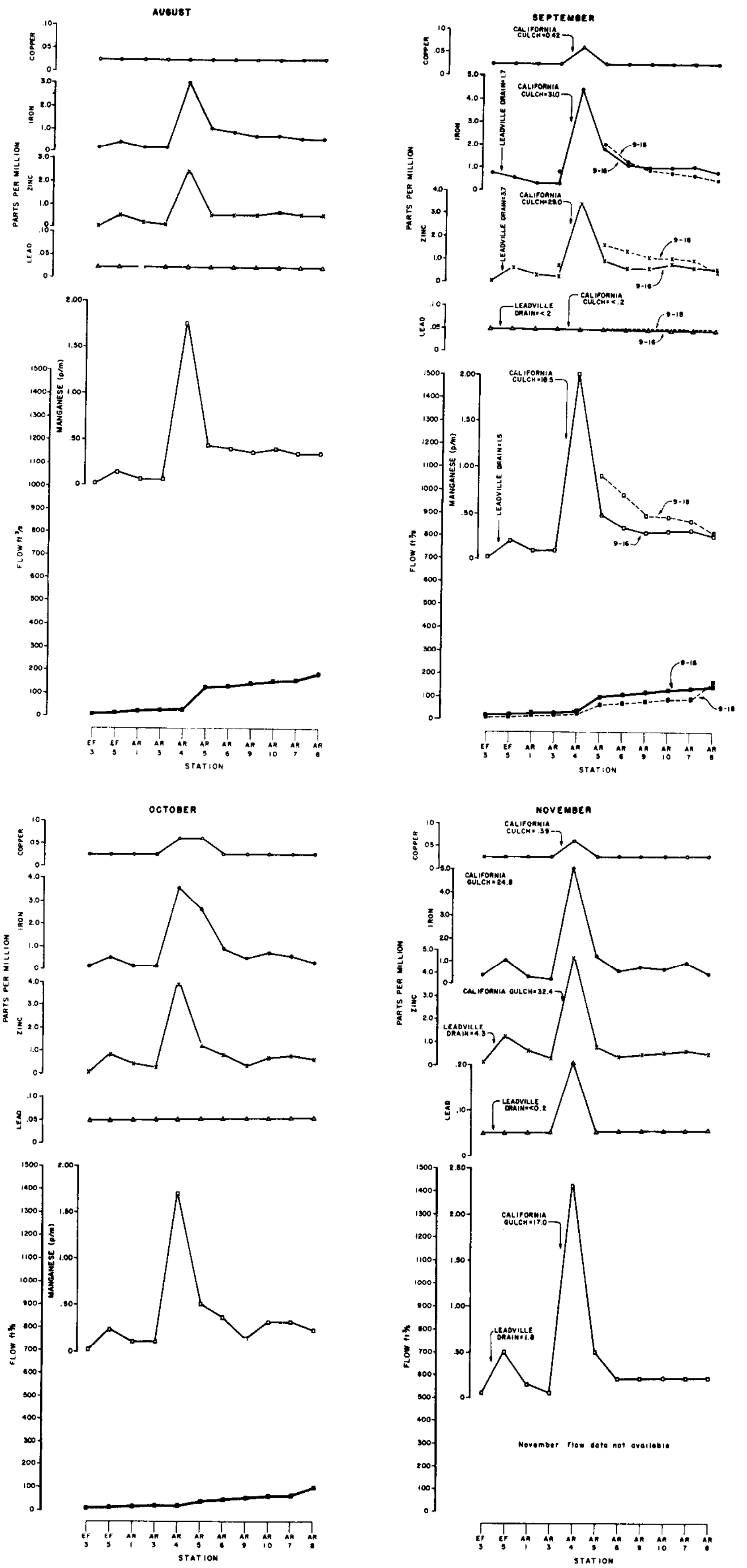


Figure 35. Heavy metal concentrations and flow August, September, October, and November—1974.

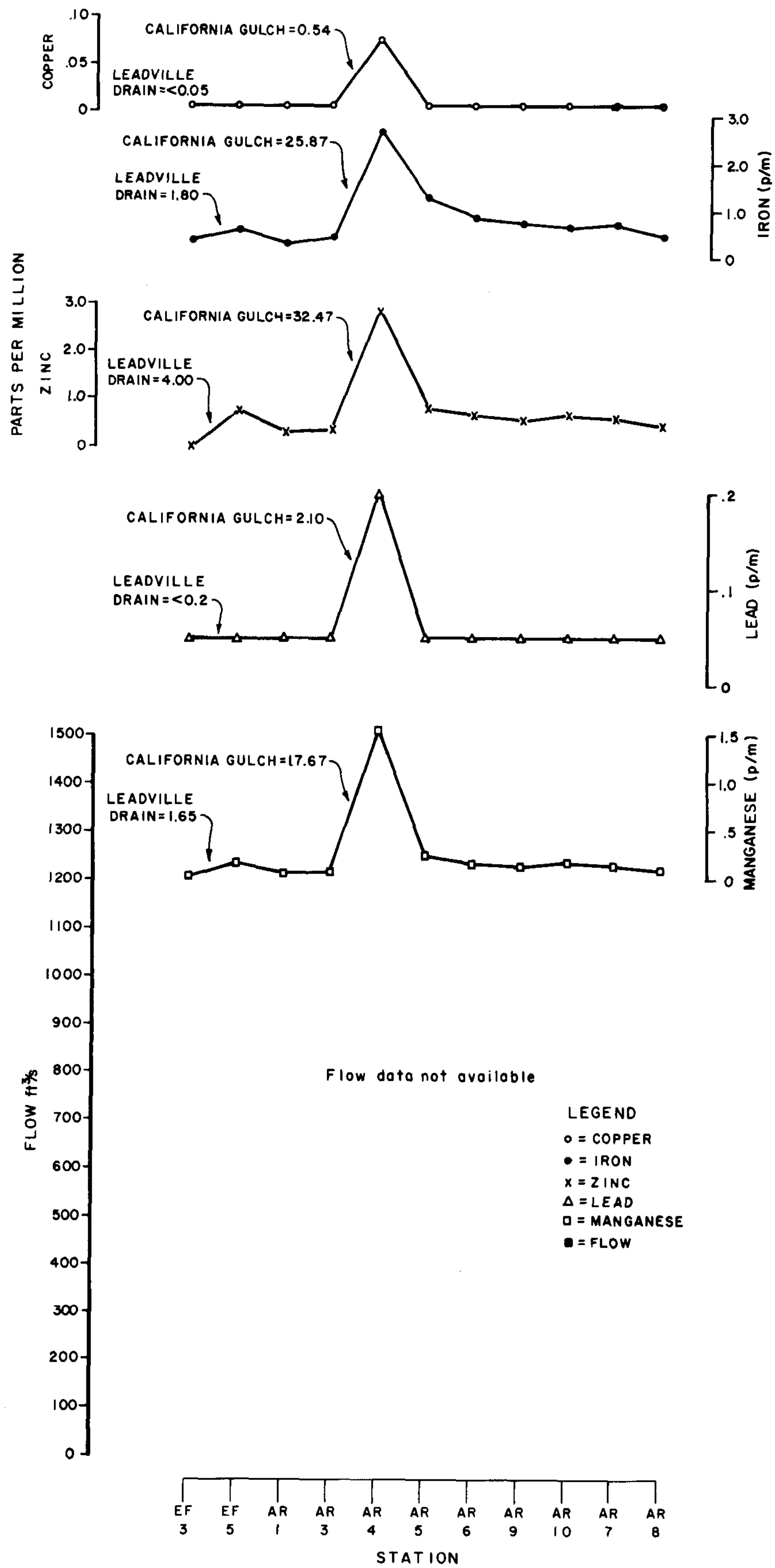


Figure 36. Average heavy metal concentrations April and November—1974.

Table 2.—*Averages of heavy metal concentrations in the upper Arkansas River, Colorado for April-November 1974*

Station	Fe	Zn	Mn	Pb	Cu
EF-3	0.36	<0.05	0.05	<0.2	<0.05
EF-5	.55	.74	.32	<.2	<.05
AR-1	.28	.31	.09	<.2	<.05
AR-3	.42	.34	.10	<.2	<.05
AR-4	2.62	2.83	1.59	≅.2	.055
AR-5	1.24	.77	.49	<.2	<.05
AR-6	.79	.64	.32	<.2	<.05
AR-9	.70	.52	.25	<.2	<.05
AR-10	.64	.64	.32	<.2	<.05
AR-7	.69	.59	.26	<.2	<.05
AR-8	.42	.41	.17	<.2	<.05
EF-4	1.80	4.00	1.65	<.2	<.05
CG-5	25.87	32.47	17.67	2.10	.54

aquatic organisms that zinc exhibits greatest toxicity. In soft water 0.1 to 1.0 p/m are toxic to some forms of aquatic life. Sinley *et al.*, (1974) reported that a chronic bioassay using juvenile rainbow trout in hard (330 p/m) and soft (25 p/m) water resulted in TL_{50} values* of 7.21 and 0.43 p/m zinc, respectively. Zinc forms insoluble compounds with the mucus that covers the gills, thus damaging the gill epithelium and internally poisoning the animal (McKee & Wolf, 1963, and their citations). The degree of toxicity that animals can tolerate varies with the animal plus the physical and chemical factors in the water (Sinley *et al.*, 1974). Goettl *et al.*, (1974) recorded a 50-percent tolerance limit (TL_{50}) for rainbow trout of between 0.41 and 0.56 p/m zinc. Nehring and Goettl (1974) found brook trout to be more than twice as resistant to zinc than rainbow. Some acclimatization to the presence of zinc is possible, and survivors from batches of fish subjected to dissolved zinc have been less susceptible to additional concentrations than fish not previously exposed (Sinley *et al.*, 1974).

The presence of copper appears to have a synergistic effect on the toxicity of zinc (Doudoroff & Katz, 1953; Duodoroff, 1957; Tarzwell, 1956; Lloyd, 1961; Eaton, 1973). Duodoroff (1957) observed that test fish in soft water could tolerate a concentration of 8 p/m zinc alone for 8 hours. However, most of the fish died within 8 hours when exposed to a solution containing only 1 p/m zinc plus 0.025 p/m copper.

Concentrations of manganese ranged from less than 0.05 p/m at EF-3 in April, June, July, August, September, and October, and AR-1 and AR-3 in June to 2.3 p/m at AR-4 in November. The average concentration of manganese over the period sampled ranged from less than 0.5 p/m at EF-3 to 1.59 p/m at AR-4 (fig. 36 and table 2). The average concentrations of manganese in Leadville Drain and California Gulch were 1.65 and 17.67 p/m, respectively. The 1962 Drinking Water Standards of the USPHS included a recommended limit of 0.05 p/m manganese. Only water from EF-3 would, on the average, pass these standards. The toxicity of manganese to fish and other aquatic life depends upon many factors. Jones (1939) gives the lethal concentration for the stickleback as 40 p/m. Schweiger (1957) reports tench, carp, and trout tolerating 15 p/m manganese for 7 days. However, the toxic action is slow and manganese does not appear to precipitate the gill secretions (McKee & Wolf, 1963). On the basis of literature surveyed by McKee and Wolf (1963), they suggest concentrations over 1.0 p/m manganese could have deleterious effects on fish and other aquatic life.

Detectable amounts of lead were not commonly found in streams of the area studied. At AR-4 in July 1974, 0.2 p/m lead was detected in the Arkansas River water. Lead was not detected in the river at any other sampling location during this study. Leadville Drain did not contain a detectable amount (0.2 p/m) of lead. Concentrations of lead in California Gulch are variable (Moran & Wentz, 1974). The average concentration of lead in California Gulch water was 2.10 p/m (fig. 26 and table 2). No lead was detected in the September 1974 sample of California Gulch water, while 3.05 p/m was detected in April 1974. The 1962 USPHS Drinking Water Standard for lead is 0.05 p/m. Unfortunately,

*Median tolerance limit is defined in *Standard Methods* (1971) as that concentration of a substance in water at which just 50 percent of the test organisms are able to survive for a specific period of exposure.

the available detection limit for lead was higher than this level in all cases except the April sampling. A 0.2 p/m detection limit was used on the remainder of the samples and only water from AR-4 showed any detectable amount of lead. Lead is considered a cumulative systemic poison which is deposited in the bones of animals. In water containing lead salts, a film of coagulated mucus forms, first over the gills, and then over the body of the fish, probably as a result of a reaction between lead and an organic constitutent of mucus (Carpenter, 1930). The death of fish is caused by suffocation resulting from this obstructive layer. In soft water, lead may be very toxic while in hard water equivalent concentrations of lead are less toxic. For example, calcium in a concentration of 50 p/m has destroyed the toxic effect of 1.0 p/m lead. The Water Pollution Research Board in England, 1961, reported that the median period of survival of rainbow trout in soft water containing dissolved lead, at 18.5^{o} C, was 18 to 24 hours at 1.6 p/m and only 10 to 12 hours at 4.0 p/m. Based on available literature, concentrations of over 0.1 p/m lead will be deleterious to fish life, especially in soft waters.

Copper was detected at AR-4 every month sampled except June and August in concentrations of 0.05 to 0.06 p/m. A concentration of 0.06 p/m was also detected at AR-5 in October 1974. No detectable amounts of copper (detectable limit = 0.05 p/m) were found in Leadville Drain water. The average concentration of copper in California Gulch was 0.54 p/m (fig. 36 and table 2). Copper is not considered to be a cumulative systemic poison like lead or mercury. Most of the copper ingested is excreted by the body and very little is retained. Thus, the 1962 Drinking Water Standards of the USPHS recommends a limit of 1.0 p/m copper for domestic use based primarily on taste. The toxicity of copper to aquatic organisms varies significantly not only with the species but also with the physical and chemical characteristics of the water, such as temperature, hardness, turbidity, and carbon dioxide content (Tabata, 1969a; 1969b; 1969c; Tabata, and Nishikaura, 1969; Rehuoldt *et al.*, 1972; and Pagen Kopf *et al.*, 1974). The sulfates of copper and zinc, and of copper and cadmium are synergistic in their toxic effect on fish (Doudoroff, 1952; McKee & Wolf, 1963; and Eaton, 1973). On the basis of literature surveyed by McKee and Wolf (1963), the recommended threshold concentrations of copper for fish and aquatic life are 0.02 p/m for freshwater and 0.05 p/m for seawater.

Undoubtedly, there are harmful concentrations of toxic substances in the Arkansas River which are contributed from drainages such as the Leadville Drain, California Gulch, Tennessee Creek, Iowa Gulch, and others which were not analyzed. For example, it is known that cadmium and silver are present in toxic amounts in California Gulch water. In addition, detection limits for some of the metals tested were not of the optimum desirability. However, based on the time and resources available, results reported herein are sufficient to satisfy the intended goals of this study of providing a strong base of information.

Of the five metals discussed above, concentrations of three—iron, zinc, and manganese, exceed, at most sampling stations, levels that are accepted by the USPHS 1962 recommended standards for drinking water. In addition, only at ER-3 and AR-1 is water of high enough quality to be totally safe to aquatic life. However, only at AR-4 do concentrations remain such that aquatic life should be almost totally eliminated. It is difficult when discussing heavy metals and their toxicity to present precise values that would preclude fish life. The toxicity of any particular substance varies with water characteristics and fish species. External factors that will influence the toxicity and absorption of metals by fish are: nature and concentration of the metal, the valence of the metal, the form in which the metal exists in the water, the associated anion, the pH of the water (a lower pH increases the effects of the metal), the time of exposure of the animal, the volume of water, whether the water is stationary or moving, the temperature of the water (a higher temperature increases the effects), the dissolved oxygen content of the water, and the nature, condition, and life stage of the fish. Thus, a safe concentration of a particular metal for each body of water should be established.

Sediment chemistry.—Sediment samples were collected at each station in May, June, July, and November, and analyzed for iron, copper, manganese, lead, zinc, and molybdenum. No molybdenum was detected in any of the samples. Station to station trends for the other five metals were fairly constant, although concentrations varied widely from month to month. Mean concentrations for each metal, in p/m on a dry weight basis, are plotted in figure 37.

In general, the sediment heavy metal concentrations exhibit trends similar to those noted for the water concentrations and the mean diversity index. Highest mean concentrations of iron (30,450 p/m), copper (381 p/m), lead (2,452 p/m), and zinc (6,540 p/m) were recorded in the sediment samples from station AR-4, just below the California Gulch inflow. The highest mean manganese concentration, however, was recorded at station AR-6 (1,325 p/m). Besides the sharp peak in heavy metal concentrations at AR-4, there is a significant accumulation indicated in the area from AR-6 to AR-7. Accumulations at these locations

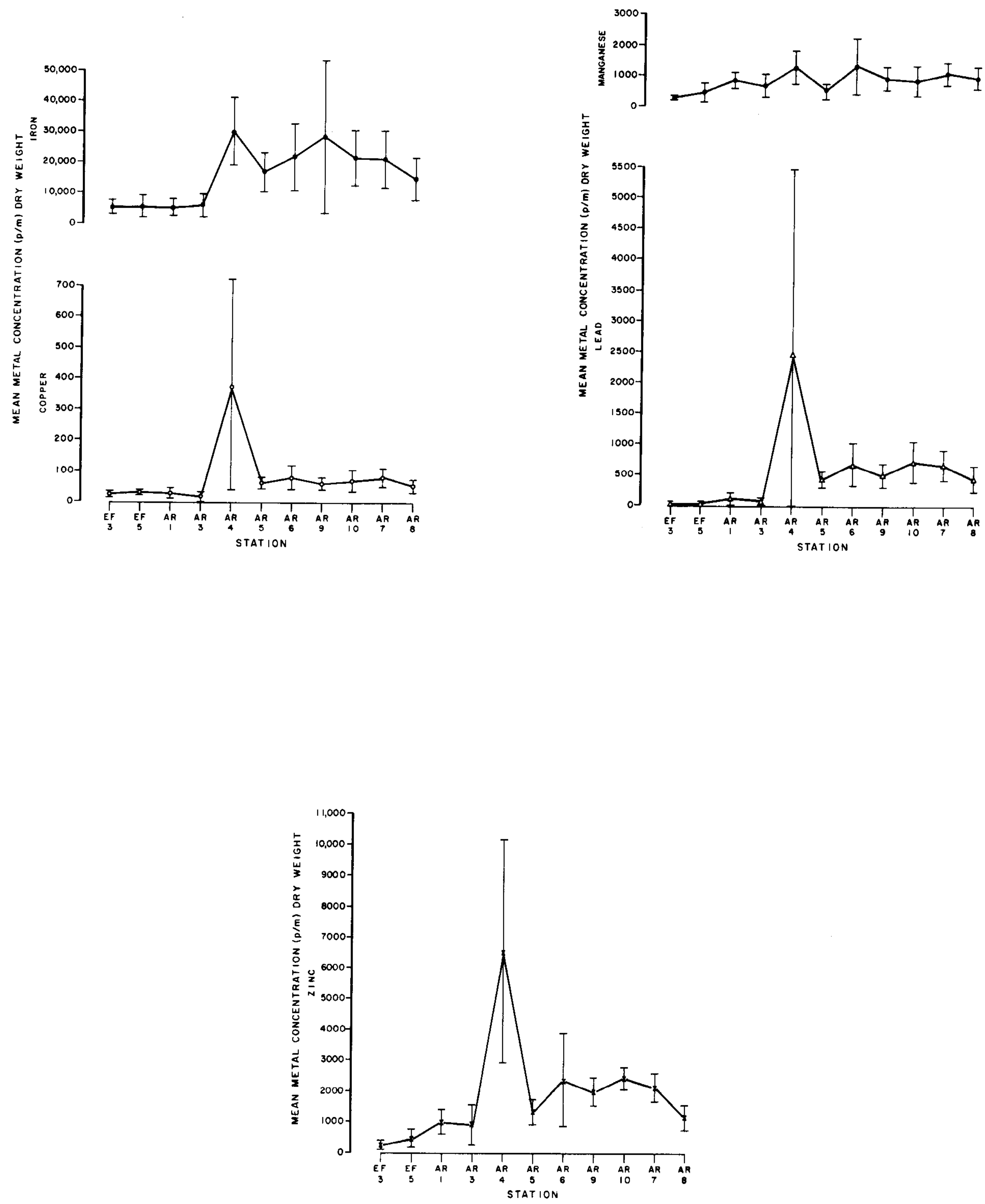


Figure 37. Average heavy metal content of sediment May through November—1974.

are reflections of the relatively high concentrations of metals found in the water as previously discussed. An effort was made to determine whether the accumulations of heavy metals below California Gulch were due to input from Iowa Gulch, intermittent stream which enters the meadows on the east side of the river in the area between AR-5 and AR-6. Mining and milling activities are presently being carried on at the Black Cloud Mine at the head of Iowa Gulch. The outflow from the U.S. Forest Service Fish Nursery at Crystal Lakes, which joins Iowa Gulch in the meadows east of the river, was also investigated as a possible pollution source. The main stem of the Arkansas River forks just above the area where these inflows occur and flows in two distinct branches for a distance of about a mile (1.61 km) before converging just above AR-6 (see fig. 5 and 6). In November, sediment samples were obtained at the Fish Nursery outlet, just above the fork in the river and on each branch just above their confluence. Results of the heavy metals analyses of these samples are given in table 3.

Maxfield, *et al.*, (1974) reported heavy metals accumulation in sediments of the southern part of the Coeur d'Alene Lake, in the Coeur d'Alene Mining District of Idaho. They recorded maximum concentrations of approximately 4,800 p/m zinc, 3,500 p/m lead, and 125 p/m copper, on a dry weight basis. While these concentrations are similar to those found below California Gulch, it is unfortunate that no biological or water-quality data were available for further comparison.

Heavy metals in bottom sediments are generally unavailable to aquatic organisms (Perhac, 1974; Lee & Plumb, 1974). Lee and Plumb (1974), however, noted in their literature review that under conditions of low pH and dissolved oxygen these metals can be released into the water and, thus, become available to the biota. In the present study, it would seem that although high concentrations of heavy metals are present in the sediments of the upper Arkansas River, pH and dissolved oxygen levels are sufficient to preclude their release into the water.

Invertebrates

Diversity indices.—Appendixes C and D contain invertebrate identifications and counts for the 1974 and 1971-73 collections, respectively. Diversity indices are listed in tables 4 through 7.

Data in table 4 indicate:

(1) an overall pattern of decline and recovery in the mean diversity index ($\bar{d}$) along the stretch of river studied.

(2) A net increase in mean diversity was noted immediately downstream from the inflows of Leadville Drain and effluent from the nearby trailer park sewage lagoon. The highest mean $\bar{d}$ value of the study (3.01) was recorded for station EF-5.

(3) Mean diversity indices at AR-1, immediately below the confluence of Tennessee Creek and the East Fork of the Arkansas, and AR-3, just above California Gulch, were generally similar to those recorded at EF-3 and EF-5.

(4) The inflow of California Gulch was followed by a decrease in $\bar{d}$ in three of the four cases where it was possible to compare station AR-3, upstream, with station AR-4, downstream. The lowest mean $\bar{d}$ of the study (1.65) was recorded for station AR-4.

(5) The combined inflow of Lake Fork and Halfmoon Creek, between AR-4 and AR-5, was followed by a recovery of $\bar{d}$ in all five sampling periods.

Table 3.—*Sediment heavy metal concentrations between stations AR-5 and AR-6*

Sampling site	Metal concentrations, p/m dry weight				
	Cu	Fe	Pb	Mn	Zn
AR-5	50	9,300	230	290	900
U.S. Fish Nursery outlet	50	2,300	40	50	150
Above fork in Arkansas River	60	20,000	760	1,400	6,000
West branch above confluence	70	15,000	780	1,500	4,800
East branch above confluence	50	9,800	390	950	2,800
AR-6	70	15,000	460	590	4,200

The highest metal concentrations were detected in sediments either above the fork in the river (iron and zinc) or on the west branch of the river (copper, lead, and manganese). No point sources were located in these areas.

Table 4.—*Monthly and mean $\bar{d}$ values for 1974 invertebrate collections*

Time	Stations											
	EF 3	EF 5	AR 1	AR 3	AR 4	AR 5	AR 6	AR 9	AR 10	AR 7	AR 8	Mean
June	2.26	[1]—	2.74	2.26	0.54	2.95	[1]—	2.93	1.06	2.70	[2] [3]0.0	2.18
July	[1]—	3.29	3.13	[1]—	1.84	2.97	2.05	[1]—	2.38	2.92	[3]2.21	2.65
August	*2.98	*3.32	2.71	3.17	1.89	*2.49	*2.36	1.02	1.96	1.45	*2.47	2.35
September	*3.42	*2.76	2.15	2.33	2.63	2.70	2.15	1.44	1.98	2.23	2.73	2.41
October	*2.20	*2.67	2.95	2.23	1.36	2.20	2.08	1.95	2.54	2.06	2.69	2.27
Mean	2.72	3.01	2.73	2.50	1.65	2.66	2.16	1.84	1.99	2.27	2.63	

[1] Artificial substrate sampler lost.
[2] One organism recovered.
[3] Not included in calculation of means
*Surber sample, to replace lost artificial substrate sampler.

Table 5.—*Monthly and mean $\bar{d}$ values for 1971-73 invertebrate collections*

Time	Stations AR 1	AR 3	AR 4	AR 5	AR 6	AR 7	AR 8	Mean
1971								
August		2.22	0.98	1.38		0.79	1.16	1.29
October	1.97	.86			0.55			1.13
1972								
September		2.70		1.07		.90	2.26	1.73
1973								
June	2.58			1.69			1.13	1.80
July	2.21	2.00	.27	1.48		.02	1.71	1.28
September	1.54	1.45	0	0		0	0	.50
Mean	2.08	1.85	.39	1.12	*.55	.43	1.25	

*One sample.
Notes: Surber sampler used for all 1971 and 1972 samples.
Artificial substrate samplers used for all 1973 samples.

(6) From AR-5 through AR-7, $\bar{d}$ values deteriorated somewhat, although no major tributaries enter the river in this area. The mean $\bar{d}$ values show a decline from 2.66 at AR-5 to 1.84 at AR-9, and then a partial recovery to 2.27 at AR-7.

(7) Because of sampling errors at AR-8 (which are discussed in detail below), only the d values for August, September, and October are considered representative of actual conditions immediately below the point where Lake Creek enters the river. In all three cases where reliable data for comparison exist, AR-8 increased in d over AR-7. The August through October mean d value of 2.63 at AR-8 indicates a recovery to approximately the conditions observed at AR-5.

The 1971-73 mean diversity indices (table 5) exhibit trends similar to those discussed above, although their absolute values are generally lower than those recorded in 1974. The differences in magnitude are probably largely caused by the use of different sampling techniques in the two studies as discussed below.

The TCI′ (trophic condition index) showed little in the way of spatial or temporal trends (table 6). Recorded values of TCI′ fell entirely in the range from 1.00 to 2.00.

Recorded values of the e (equitability index) were scattered throughout the range from 0.38 to 1.30 (table 7). Mean e values at the locations sampled ranged from 0.73 to 1.12, while monthly means varied from 0.79 to 0.98.

A stream ecosystem is composed of all the biological, chemical, and physical factors within a given area of the stream, as well as all their interactions. These interacting factors give rise to a characteristic community of organisms which changes with time until it is in equilibrium with the nonliving components of the ecosystem. This change, or succession, of communities is usually in the direction of increasing structural complexity, with the "equilibrium" community frequently being composed of a few species having many individuals and many other species having only a few individuals: the so-called MacArthur "broken-stick" model of species distribution (Lloyd & Ghelardi, 1964; Wilhm & Dorris, 1968; Weber, 1973). A disturbance of the ecosystem, such as pollutional stress, usually results in two changes in community structure:

(1) a reduction of the total number of species, as those species that are intolerant to the disturbance are eliminated, and

(2) because of reduced competition, an increase in the numbers of individuals of those species that are able to survive the disturbance (Cairns *et al.*, 1973).

The concepts outlined above have important implications for assessment of water quality. Tests for

TABLE 6.—*Monthly and mean TCI′ values for 1974 invertebrate collections*

Time	Stations											Mean
	EF 3	EF 5	AR 1	AR 3	AR 4	AR 5	AR 6	AR 9	AR 10	AR 7	AR 8	
June	1.86	[1]—	1.52	1.72	1.13	1.77	[1]—	1.80	1.97	1.83	[2,3]1.00	1.70
July	[1]—	1.57	1.84	[1]—	1.71	1.88	1.92	[1]—	1.56	1.83	[3]1.67	1.76
August	*1.76	*1.80	1.49	1.71	1.95	*1.77	*1.93	1.26	1.84	1.89	*1.92	1.76
September	*1.61	*1.89	1.59	1.98	1.98	1.93	1.90	1.24	1.75	1.80	1.72	1.76
October	*1.75	*1.79	1.94	2.00	1.99	1.98	1.98	2.00	1.77	1.93	1.84	1.91
Mean	1.75	1.76	1.68	1.85	1.75	1.87	1.93	1.58	1.78	1.86	1.83	

[1] Artificial substrate sampler lost.
[2] One organism recovered.
[3] Not included in calculation of means.
*Suber sample, to replace lost artificial substrate sampler.

TABLE 7.—*Monthly and mean e values for 1974 invertebrate collections*

Time	Stations											Mean
	EF 3	EF 5	AR 1	AR 3	AR 4	AR 5	AR 6	AR 9	AR 10	AR 7	AR 8	
June	0.38	[1]—	0.92	0.72	0.80	1.08	[1]—	0.83	0.42	1.13	[2]—	0.79
July	[1]—	1.00	.83	[1]—	1.17	.85	1.10	[1]—	.88	1.06	[3].52	.98
August	*1.24	*1.30	.82	.98	.69	*.64	*.99	.81	.73	.85	*1.08	.92
September	*1.10	*1.05	.84	.97	.95	.75	.54	.68	.74	1.05	1.15	.89
October	.76	*.97	1.08	.70	.53	.56	.70	1.27	.89	.92	1.12	.86
Mean	.87	1.08	.90	.84	.83	.78	.83	.90	.73	1.00	1.12	

[1] Artificial substrate sampler lost.
[2] One organism recovered.
[3] Not included in calculation of means.
*Surber sample, to replace lost artificial substrate sampler.

discrete chemical and physical water-quality parameters, while important, can overlook several problems; e.g., synergistic or antagonistic effects, very low-level concentrations of long duration, and pulses of high concentration between sampling periods. The organisms that make up the stream community, however, respond to their total environment, so that their "well-being," as reflected by their community structure and its changes, is a good indicator of the overall health of the stream. It is valuable, then, to supplement the standard physical and chemical tests with some information on the stream community. One of the simplest, and yet meaningful, methods of obtaining this information is through the use of diversity indices.

Wilhm and Dorris (1968) describe diversity indices as mathematical expressions which describe community structure and permit summarization of large amounts of information about numbers and kinds of organisms. A diversity index has two components: (1) the actual number of different groups of organisms, or taxa, present in the community, and (2) the numerical distribution of the individual organisms among the various taxa (Gaufin, 1973). Maximum diversity occurs when each individual organism belongs to a different taxon, while minimum diversity occurs when all the individuals belong to the same taxon; in other words, diversity is directly related to the structural complexity of the community.

Although there are several diversity indices, those derived from information theory (Margalef, 1957; Wilhm & Dorris, 1968) are probably most widely used and recognized. Of these, the most common expression is that of equation (1) in the section on "Methods of Analysis" for mean diversity, or average diversity per individual ($\bar{d}$). This index is independent of sample size, and only requires for its application that organisms be recognized and number per taxon be determined.

On the basis of various studies of benthic macroinvertebrate communities in streams receiving domestic, oil refinery, and oil field pollution, Wilhm and Dorris (1968) conclude that pollution results in a change in the community structure which is reflected as a depression in $\bar{d}$. Values of $\bar{d}$ less than one were reported in areas of "heavy" pollution, values from 1 to 3 in areas of "moderate" pollution, and values between 3 and 4 in "clean water" areas.

Dills and Rogers (1974) studied the applicability of using the bottom macroinvertebrate community structure, as reflected by $\bar{d}$, to evaluate stream conditions caused by acid mine drainage in Crane Creek Basin, Alabama. In addition to various physicochemical tests, a Surber sampler was used to make biweekly invertebrate collections at 10 stations over a 1-year period. Results showed that varying degrees of acid mine pollution were reflected by changes in $\bar{d}$, with stations located near areas of acid production being consistently lowest in diversity. Stations on the "acidic tributaries" of Crane Creek had mean annual values of $\bar{d}$ ranging from 1.64 to 1.89, while the "clean water" station above these tributaries had a mean annual $\bar{d}$ of 3.11. This last value dropped to 1.94 at the station below the acidic tributary inflows.

Finally, Wilhm (1970), using data from D. A. Bingham (1968), calculated the following $\bar{d}$'s for Surber samples from four "clean water streams" in Colorado:

Stream	Time	$\bar{d}$
Dolores River	August	2.81
Roaring Fork	April	2.98
Gunnison River	July	3.48
Castle Creek	April	4.00

Figure 38 summarizes the mean $\bar{d}$'s recorded at each station in both the 1974 and 1971-73 studies of heavy

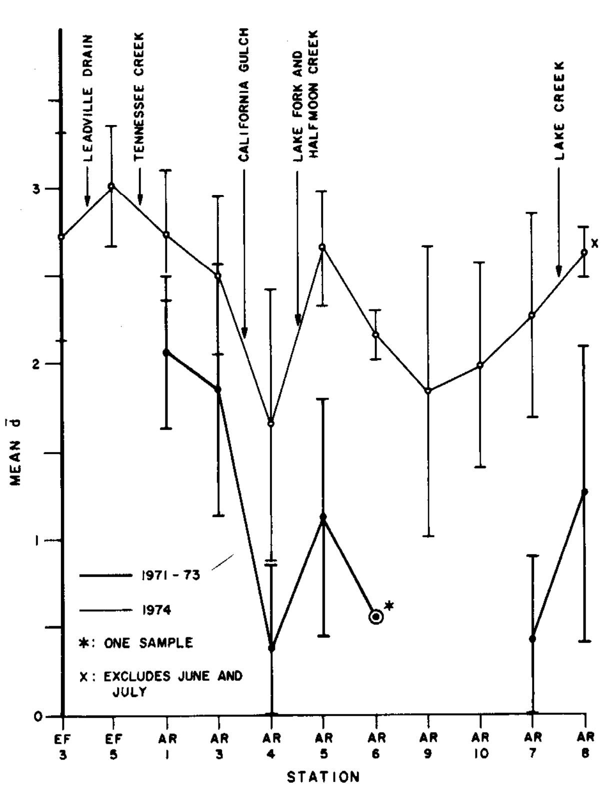


Figure 38. Mean values of $\bar{d}$ from the Arkansas River, Colorado.

metals pollution in the Arkansas River in the vicinity of Leadville, Colo. Data in this figure indicate four main areas of impact: The Leadville Drain area, the California Gulch area, the stretch between the Lake Fork-Halfmoon Creek inflow and Lake Creek, and the Lake Creek area.

In comparison with literature cited above, the range of $\bar{d}$ calculated for EF-3, EF-5, AR-1, and AR-3 indicates the river in this area to be "clean" to "moderately polluted." Although diversity at EF-5 is apparently not adversely affected by Leadville Drain effluent, and in fact, shows a net increase, it should be noted that along with this drainage water, effluent from a trailer park sewage lagoon also enters at this point and the effects of the two inputs were not separated in this study. It is possible that the sewage effluent serves as a "buffer" against adverse effects of the drainage water, while providing nutrients to the benthic organisms.

The inflow of California Gulch has a definite deleterious effect on the structure of the benthic macroinvertebrate community, as reflected by a sharp decrease in diversity at AR-4 relative to AR-3. At AR-5, however, the benthic community recovers to the point that diversity at this station is approximately equal to that at AR-3, above California Gulch. The chief factor in this rather dramatic recovery is apparently the dilutional effect of the combined inflow of the Lake Fork and Halfmoon Creek, which enters the river about 0.7 miles (1.13 km) above AR-5.

From the point where the Lake Fork and Halfmoon Creek enter the river, above AR-5, to the confluence of Lake Creek and the Arkansas, about 100 yards (91.44 m) below AR-7, there are no major tributaries. Tributary flow in this stretch consists of small creeks and intermittent streams, and runoff from surrounding alluvial hills and marshy meadows. Diversity in this area (AR-6, AR-9, AR-10, and AR-7) declines from levels noted at AR-5, although it usually recovers somewhat by AR-7. No specific point sources of pollutional stress were identified to account for this general decline, although, based on mean $\bar{d}$ values, AR-9 and AR-10 appear to be the most affected.

The macroinvertebrate collections of June and July at AR-8 do not accurately reflect the influence of Lake Creek on the Arkansas River. The position of the sampler over a cobble bottom exposed to fast-moving flow precluded effective colonization of the substrate by invertebrates. In 1973, the basket sampler was located off a willow-covered bank about 10 feet (3.05 m) downstream from the 1974 site, while the 1971-72 Surber samples were collected off a gravel bar approximately 100 feet (30.48 m) farther downstream. After the basket was smashed by a large cobble in August 1974, a Surber sample was taken to fill the data gap and a small rock barrier was placed above the basket for the September and October sampling periods. These last three collections are more representative than those of June and July, and along with the 1971-73 data, indicate an increase in diversity relative to AR-7. It is apparent that the dilutional effect of Lake Creek restores the benthic community to approximately the level of structural complexity observed at AR-5.

There is an obvious difference in absolute values between $\bar{d}$'s obtained in 1974, and those obtained during the 1971-73 stream study. Lower 1971-73 $\bar{d}$ values are probably attributable to the differences in sampling techniques, particularly the difference in artificial substrate samplers. Beak, *et al.*, (1973) point out that the number of individual organisms colonizing a basket sampler is related to the number of voids in the filling, rather than to the surface area of the material. Because of the better attachment surfaces of bark chips and the absence of the molar action of rocks, Bergersen and Galat (1974) consistently found a larger number of macroinvertebrates in bark-filled baskets relative to rock-filled baskets. It should also be noted that porcelain ball and rock-filled baskets used in 1973 rested directly on the stream bottom and often became completely clogged with sediment.

Beak, *et al.*, (1973) also compare the effectiveness of various artificial substrate samplers with Surber samples obtained at the same time and conclude that the representation of respectable numbers of pollution tolerant and pollution sensitive taxa, their relative abundances, and the species diversity are comparable in results from both types of samplers. They add that, with regard to pollution assessment, both sets of data yield identical conclusions about the status of the aquatic environments in question.

Trophic condition (TCI') is an indicator of the benthic community's tolerance to organic pollution (Weber, 1973; Gaufin, 1973). A TCI' value of 0 indicates that all the organisms in a collection belong to taxa relatively intolerant of even slight reductions in dissolved oxygen; 1.0 indicates a collection of organisms having a wide range of tolerance and often associated with moderate levels of organic pollution; and 2.0 indicates organisms capable of living under anaerobic conditions and often associated with gross organic pollution. TCI' values recorded here indicate that all collections were composed of organisms considered relatively tolerant to organic pollution and reduced dissolved oxygen levels.

Equitability (e) is a measure of how closely a particular community's structure conforms to the MacArthur "broken-stick" model of species distribution (Lloyd & Ghelardi, 1974; Weber, 1973). Although number of species depends primarily on the structural diversity of a habitat, equitability is more sensitive to the stability of physical conditions (Lloyd & Ghelardi, 1964). Weber (1973), however, concludes that estimates of equitability based on samples containing less than 100 specimens should be evaluated with caution, if at all. The equitability values calculated in this study show no significant trends, although mean values all approach 1.0. This might suggest that these stream communities have developed in response to a relatively stable environment.

Heavy metal content.—Upon completion of diversity measurements, the benthic macroinvertebrate collections were sent to the chemistry laboratory for determination of heavy metal content. The entire monthly collection at each station was lumped into one sample to be analyzed for copper, iron, lead, zinc, manganese, and molybdenum content. No molybdenum was detected in any of the invertebrate samples. Results of the other five analyses are listed in tables 8 to 13. All results are in parts per million on a dry-weight basis.

Copper, iron, lead, zinc, and manganese content of 1974 invertebrate collections are tabulated respectively in tables 8 through 12. The five sets of invertebrate metal contents fall within the following ranges in p/m of dry weight: 20-8,870 for copper, 820-47,700 for iron, 20-152,000 for lead, 630-9,500 for zinc, and 40-9,100 for manganese. Highest mean concentrations were: 2,320 p/m copper at EF-3, 18,620 p/m iron at AR-4, 38,128 p/m lead at AR-8, 6,250 p/m zinc at AR-9, and 2,743 p/m manganese at EF-3. No spatial or temporal trends are evident in the data.

Table 13 lists mean heavy metal content of 1971-73 invertebrate collections by station and month. The highest mean concentrations were: 1,413 p/m copper and 27,400 p/m iron at AR-4 and 1,425 p/m lead, 8,225 p/m zinc, and 2,310 p/m manganese at AR-7. With the exception of lead, these mean heavy metal concentrations are similar to those of 1974 collections. Once again, no significant data trends are discernible.

To facilitate comparison with heavy metal contents of water and fish samples, the 1974 concentrations were converted to a wet-weight basis by assuming an average invertebrate moisture content of 80 percent. Results of these comparisons are in table 14. The relatively high heavy metal concentrations found in invertebrate samples from the study area reinforces the conclusion that living organisms concentrate heavy metals from their environment in their body tissues. Aquatic insects are less sensitive to heavy metals in water than fish or plants (Warnick & Bell, 1969; Gaufin, 1973). Studies in Wales show stonefly nymphs (Plecoptera), mayfly nymphs (Ephemeroptera) and some midge larvae (Diptera) to be very resistant to both lead and zinc in water. These organisms, along with caddisfly larvae (Trichoptera) were able to tolerate zinc concentrations of nearly 60 p/m. On the other hand, worms, leeches, crustaceans, molluscs, fish, rooted plants, and algae were very susceptible to these metals (Jones, 1940a, 1940b, 1949, 1958).

Bioassays by Warnick and Bell (1969) on three species (stonefly, *Acroneuria lycorias*; mayfly, *Ephemerella subvaria*; and caddisfly, *Hydropsyche betteni*) support, Jones' data with respect to zinc and lead. That is, all three insects lived beyond the 96-hour test period in water containing up to 64.0 p/m zinc or lead. Caddisfly were also unaffected by 96-hour exposures to concentrations of up to 64.0 p/m copper or iron.

Mayfly, however, had a 48-hour median tolerance limit (TL_m) of 0.32 p/m copper and a 96-hour TL_m of 0.32 p/m iron. Stoneflies, while resistant to the maximum test concentrations of iron, showed a 96-hour TL_m of 8.3 p/m copper.

The types of invertebrates represented in the collections used in the present study area are listed in table 15. Two points are apparent from an examination of these data:

1. Insects, as a group, accounted for over 99 percent of the organisms in both collections.

2. Trichoptera predominated among the insects in both collections.

These results are consistent with the data discussed above on the heavy metals tolerance of insects in general and Trichoptera in particular.

The pattern of dominance displayed in table 15 suggests three possible reasons for relatively high heavy metal concentrations in invertebrate samples. First, Trichoptera larvae surround themselves with cases built from sediment and debris. In larvae from streams polluted with heavy metals, these cases could be expected to contain high concentrations. Second, it is possible that the exoskeleton of insects acts as a "sink" for heavy metals, thus allowing them to accumulate concentrations that would eliminate other organisms. Finally, many of these insect nymphs and larvae are predators or detritus-feeders (Pennak, 1953; Gaufin, 1973) and, thus, could be expected to accumulate more heavy metals than herbivores.

TABLE 8.—*1974 Monthly and mean invertebrate copper content p/m dry weight*

Time	Stations											Mean
	EF 3	EF 5	AR 1	AR 3	AR 4	AR 5	AR 6	AR 9	AR 10	AR 7	AR 8	
June	190	[1]—	190	100	490	217	[1]—	175	160	180	*280	216
July	[1]—	150	160	[1]—	1,000	160	330	[1]—	270	380	190	330
August	170	110	180	110	100	150	130	220	100	70	150	135
September	50	70	50	50	70	60	70	90	180	180	260	130
October	8,870	[2]—	[2]—	20	130	40	70	[2]—	[2]—	[2]—	[2]—	1,826
Mean	2,320	110	145	70	358	125	150	165	178	203	220	

[1] No sample obtained.
[2] Sample contaminated.
*One organism.

TABLE 9.—*1974 Monthly and mean invertebrate iron content p/m dry weight*

Time	Stations											Mean
	EF 3	EF 5	AR 1	AR 3	AR 4	AR 5	AR 6	AR 9	AR 10	AR 7	AR 8	
June	6,200	[1]—	11,400	820	47,700	8,400	[1]—	7,750	1,100	7,900	*38,400	13,742
July	[1]—	8,900	1,500	[1]—	21,000	3,000	10,600	[1]—	5,300	5,600	5,800	7,713
August	1,200	3,800	11,800	6,900	12,300	1,200	8,100	1,400	13,600	3,700	5,200	6,291
September	5,400	11,900	6,000	7,900	5,800	3,800	5,100	2,800	1,400	9,800	5,600	5,955
October	7,600	[2]—	[2]—	3,000	6,300	2,800	6,000	[2]—	[2]—	[2]—	[2]—	5,140
Mean	5,100	8,200	7,675	4,655	18,620	3,840	7,450	4,925	5,350	6,750	13,750	

[1] No sample obtained.
[2] Sample contaminated.
*One organism.

TABLE 10.—*1974 Monthly and mean invertebrate lead content p/m dry weight*

Time	Stations											Mean
	EF 3	EF 5	AR 1	AR 3	AR 4	AR 5	AR 6	AR 9	AR 10	AR 7	AR 8	
June	260	[1]—	190	40	740	640	[1]—	17,100	120	970	*152,000	18,916
July	[1]—	210	390	[1]—	470	110	430	[1]—	370	350	280	326
August	20	70	270	140	540	60	490	140	13,100	60	40	1,357
September	20	60	60	60	90	50	70	20	740	310	190	152
October	260	[2]—	—	40	190	30	100	[2]—	[2]—	[2]—	[2]—	124
Mean	140	113	228	70	406	178	273	8,590	3,583	423	38,128	

[1]No sample obtained.
[2]Sample contaminated.
*One organism.

TABLE 11.—*1974 Monthly and mean invertebrate zinc content p/m dry weight*

Time	Stations											Mean
	EF 3	EF 5	AR 1	AR 3	AR 4	AR 5	AR 6	AR 9	AR 10	AR 7	AR 8	
June	2,200	[1]—	3,400	1,800	7,800	6,700	[1]—	7,000	1,500	5,600	*9,500	5,250
July	[1]—	970	720	[1]—	2,400	710	630	[1]—	1,400	1,400	680	1,114
August	2,300	4,000	9,100	5,200	7,600	1,500	6,500	4,900	8,100	1,100	2,500	4,800
September	2,300	4,700	8,800	6,900	4,100	3,600	3,400	6,100	8,800	7,900	7,700	5,845
October	2,900	[2]—	[2]—	2,600	7,000	2,100	4,900	[2]—	[2]—	[2]—	[2]—	3,700
Mean	2,175	3,223	5,505	4,125	5,780	2,922	3,858	6,250	4,950	4,000	5;095	

[1]No samples obtained.
[2]Sample contaminated.
*One organism.

TABLE 12.—*1974 Monthly and mean invertebrate manganese content*
p/m dry weight

Time	Stations EF 3	EF 5	AR 1	AR 3	AR 4	AR 5	AR 6	AR 9	AR 10	AR 7	AR 8	Mean
June	360	[1]—	1,500	480	2,800	1,300	[1]—	4,550	190	2,300	*50	1,808
July	[1]—	250	240	[1]—	610	800	560	[1]—	1,400	670	430	620
August	9,100	3,300	3,000	2,100	6,900	190	3,600	200	5,500	740	670	3,209
September	520	880	2,100	1,900	70	1,400	1,100	40	1,800	1,400	360	1,052
October	990	[2]—	[2]—	610	760	420	980	[2]—	[2]—	[2]—	[2]—	752
Mean	2,743	1,477	1,710	1,273	2,228	822	1,560	2,335	2,223	1,278	377	

[1] No samples obtained.
[2] Sample contaminated.
*One organism.

Table 13.—*1971-73 Mean invertebrate metal content*
p/m dry weight

Metals	Stations AR 1	AR 3	AR 4	AR 5	*AR 6	AR 7	AR 8	Months June	July	August	September	October
Copper	301	228	1,413	240	140	555	222	172	285	902	386	335
Iron	5,564	10,067	27,400	11,120	24,900	20,750	13,500	4,483	11,833	15,820	18,811	9,138
Lead	62	80	280	346	850	1,425	770	143	430	854	531	185
Zinc	1,471	1,662	2,637	3,788	1,500	8,225	3,620	1,970	1,692	3,940	5,759	900
Manganese	209	233	197	1,058	290	2,310	456	252	333	402	1,556	201

*One sample

Table 14.—*Comparison of heavy metal concentrations in water, fish, and invertebrates for May-November 1974*

Metal	Maximum water concentration[1] (p/m)	Highest average fish concentration[2] (p/m, wet weight)	Average invertebrate sample concentration[3] (p/m, wet weight)[4]
Copper	0.06	4.21	74
Iron	5.0	15.38	1,599
Lead	.20	1.95	872
Zinc	4.6	76	864
Manganese	2.3	17	314

[1] All at station AR-4, November 1974
[2] Species vary
[3] Average of all 1974 samples
[4] Assumes 80 percent moisture content

Table 15.—*Invertebrate types represented in collections of 1971-73 and 1974 from the upper Arkansas River, Colorado*

Invertebrates	Insects (percent of samples)		"Worms" (percent of samples)		Arachnids (percent of samples)	
	1971-73	1974	1971-73	1974	1971-73	1974
Nematoda (Roundworms)			0.3	0.1		
Oligochaeta (Aquatic earthworms)				.2		
Hydracarina (Water mites)						0.3
Plecoptera* (Stoneflies)	2.1	26.2				
Ephemeroptera* (Mayflies)	6.4	9.9				
Trichoptera* (Caddisflies)	86.0	36.0				
Coleoptera (Beetles)		1.0				
Diptera* (Two-winged flies)	5.2	26.3				
Totals	99.7	99.4	.3	.3	0	.3

*Predominantly nymphs or larvae

Fish

Numbers and species composition.—Figure 39 presents results of fish sampling of the upper Arkansas River, Colorado, during September 1974. Six locations at or near the regular monthly sampling stations were sampled. The thick, dark line in figure 39 connects data that represent total number of all species collected with equal effort at the stations indicated. With equal effort, fewer fish were collected at downstream stations. In 100 yards of stream at EF-1, the most upstream station, 72 fish were collected; at AR-7, the most downstream station, only 12 were collected. There is a significant drop in number of fish collected from EF-1 to EF-6. Leadville Drain contributes effluent between these two stations. The rise in number from EF-6 to AR-3 results from the freshening effect of Tennessee Creek. Between AR-3 and AR-4 there is a drastic drop in number of fish collected. California Gulch contributes effluent between these two stations. Only one brook trout, about 300 mm in total length with a deposit caked on its gills, was collected in 400 yards of stream sampled at AR-4. Between AR-4 and AR-5 the relatively pure flow of Lake Fork, including the contribution from Turquoise Reservoir, joins the Arkansas River resulting in a partial recovery in number of fish at AR-5. A total of 39 fish was collected at AR-5. Flows were quite high and it is probable that many more fish escaped being collected at this station than at any other. However, many of the fish that were collected at AR-5 most likely were residents of Lake Fork. When flows out of Turquoise Reservoir were lowered to facilitate the fish-shocking operation, fish that had normally resided in Lake Fork probably moved downstream into the Arkansas River at AR-5. Thus, the actual resident fish population at AR-5 may be lower than our effort shows. Between AR-5 and AR-7 there is a significant drop in number of fish collected. As indicated previously, water quality deteriorates somewhat between AR-5 and AR-7, the reason being that there seems to be diverse inputs of heavy metal pollution from the west into the Arkansas River somewhere between AR-5 and AR-7.

The species of fish collected were brown, brook, and rainbow trout plus one sucker. Brown trout (*Salmo trutta* L.) was the most common species collected, and was present at all stations except AR-4 and followed the general pattern of distribution (fig. 39). Brook trout (*Salvelinus fontinalis* [Mitchill]) was the next most common species of fish collected, and was collected from every station except AR-7. Juvenile brook trout were most abundant at EF-1. Rainbow trout (*Salmo gairdneri* Richardson) were collected only at AR-5. Rainbow trout would be expected to be found at other stations also. However, Goettl *et al.*, (1974) found brook trout about twice as resistant to zinc as rainbow. Thus, the presence of zinc at most stations may preclude the existence of rainbow trout.

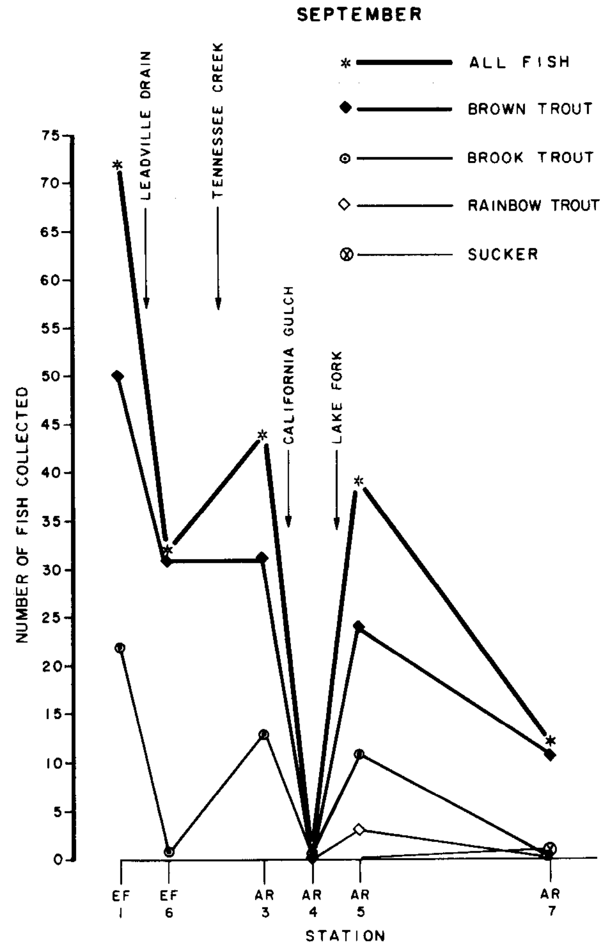


Figure 39. Results of fish sampling of the Arkansas River, Colorado, September—1974.

Only one sucker, the white sucker (*Catostomus commersoni* [Lacepede]), was collected. It was found at AR-7. This species is the only one collected which is historically native, the trout collected being introduced species. It is surprising that suckers were not more common. The metal tolerance of suckers is unknown, but the presence of metals could be the reason for their diminution. However, suckers are known to migrate and be most abundant in headwater areas in the spring, which is their spawning period. At other times they seem to seek pools, ponds, and lakes. The presently discussed survey was in September.

Based on this survey, it is apparent that fish populations are low where heavy metal pollution is present, as evidenced in figure 39. This section of the

Arkansas River does not appear to be a good fishery, with the exception of EF-3 where mostly juveniles are found. Data indicate that fishing conditions at AR-3 and AR-5 may be fair. However, it is suspected that AR-5 fish are probably residents of Lake Fork. Thus, AR-5 may also be a questionable fishery. If the major sources of pollution, that is, Leadville Drain, California Gulch, and the diverse flows between AR-5 and AR-7, were cleaned up, this section of the Arkansas River could soon be rated as an excellent fishery.

Heavy metal content.—Figures 40 and 41 present results of heavy metal analysis of fish flesh and skin. These data are presented by species in parts per million on a wet-weight basis. These data indicate the increase in heavy metal concentration downstream. There is a relatively high concentration of each metal in the brook trout specimens collected at AR-4 where heavy metal pollution is also highest. The average concentration of the metals tested by species are in table 16. Brown trout contained, on the average, more zinc, manganese, and cadmium in their flesh and skin than did brook trout while the opposite was true of iron and copper. Sample sizes of rainbow trout and suckers were too low to reach conclusions.

Tong *et al.*, (1974) found 0.24 p/m iron in the muscle of the lake trout (*Salvelinus namaycush*) in Lake Cayuga, New York. The values for trout from the Arkansas River are significantly higher. This would be expected where iron concentrations in the water are excessive as they are in the Arkansas River.

Jeng and Huang (1973) found 0.9 to 2.7 p/m copper in the common carp (*Cyprinus carpio*), 0.9 to 1.3 p/m copper in grass carp (*Ctenopharyngodon idellus*), 0.015 to 1.6 p/m in tilapia (*Tilapia mossambica*), and 0.7 to 7.4 p/m copper in the silver carp (*Hypophthalmichtys molitrix*). Windon *et al.*, (1973) found about 0.08 to 5.75 p/m in Osteichthys (boney fishes).

These values correspond somewhat with those of trout from the Arkansas River.

Tong *et al.*, (1974) found a range of 0.025 to 0.05 p/m manganese in lake trout (*Salvelinus namaycush*) aged 1 to 12 years from Lake Cayuga, New York. Uthe and Bligh (1971) found 0.66 to 2.98 p/m manganese in lake whitefish (*Coregonus clupeaformis*), 0.02 p/m in rainbow smelt (*Osmerus mordax*), and 3.16 p/m in northern pike (*Esox lucius*). Concentrations of manganese in trout from the Arkansas River were significantly higher, which is expected since manganese concentrations in the Arkansas River are extreme.

Jeng and Huang (1973) found from less than 0.1 p/m to 0.4 p/m lead in cultured fish of Taiwan, while Tong *et al.*, (1974) found 0.011 p/m lead in lake trout (*Salvelinus namaycush*) from Lake Cayuga, New York. Goettl *et al.*, (1974) found about 2.05 p/m (8.2 p/m dry weight) lead and 3.75 p/m (15.0 p/m dry weight) lead in brown trout from Ten-Mile Creek near Climax, Colo., and the Animas River near Silverton, Colo., respectively. Data from Goettl *et al.*, (1974) are transposed to wet-weight basis on the assumption that 75 percent of the animal is water. Based on that assumption, their results and those of this study are comparable. Results reported in Goettl *et al.*, (1974) were from even more heavily polluted environments, explaining their somewhat higher results. However, it must be recognized that there may be several other factors involved when comparing values. Concentrations in trout from Colorado were somewhat higher than those found by Jeng and Huang (1973) and Tong *et al.*, (1974), again resulting from abnormal concentrations of lead in the Colorado aquatic environments.

Portmann (1972) found from 4.6 to 6.2 p/m zinc in cod, whiting, plaice, herring, and mackerel. Holden and Topping (1972) found from 1.7 to 14.7 p/m zinc in haddock, plaice, herring, mackerel, saithe, whiting, and dogfish. Eustace (1974) found 4.6 to 6.2 p/m zinc in fish from Lake Erie. Jeng and Huang (1973) found 6 to 92 p/m zinc in Taiwan's cultured fish. Tong *et al.*, (1974) found from 0.02 to 0.432 p/m zinc in lake trout (*Salvelinus namaycush*) from Lake Cayuga, New York. Windon *et al.*, (1973) found about 1.75 to 99.2 p/m zinc in Osteichthys. Uthe and Bligh (1971) found 12 to 19 p/m and 20 p/m zinc in lake whitefish and rainbow smelt, respectively. Goettl *et al.*, (1974) found 94 p/m (376 p/m dry weight) zinc and 124 p/m (495 p/m dry weight) zinc in brown trout from Ten-Mile Creek near Climax, Colo., and the Animas River near Silverton, Colo., respectively. They found 87 p/m (351 p/m dry weight) zinc and 122 p/m (486 p/m dry weight) zinc in brook trout from the same locations, respectively. Data from Goettl *et al.*, (1974) for zinc were transposed to wet-weight basis for comparison purposes by assuming 75 percent of the animal is water. Based on that assumption, data from this study and from Goettl *et al.*, (1974) compare favorably. Also, concentrations of zinc in fish from the Arkansas River fall within the range of data reported by Jeng and Huang (1973) and Windon *et al.*, (1973), but are much higher than those reported by Portmann (1972), Holden and Topping (1972), Eustace (1974), Tong *et al.*, (1974), or Uthe and Bligh (1971). The relatively high values for zinc in Arkansas River fish is attributable to the abnormal amounts in the aquatic environment.

Jeng and Huang (1973) found from 0.01 to 0.1 p/m cadmium in Taiwan's cultured fish. Portmann (1972)

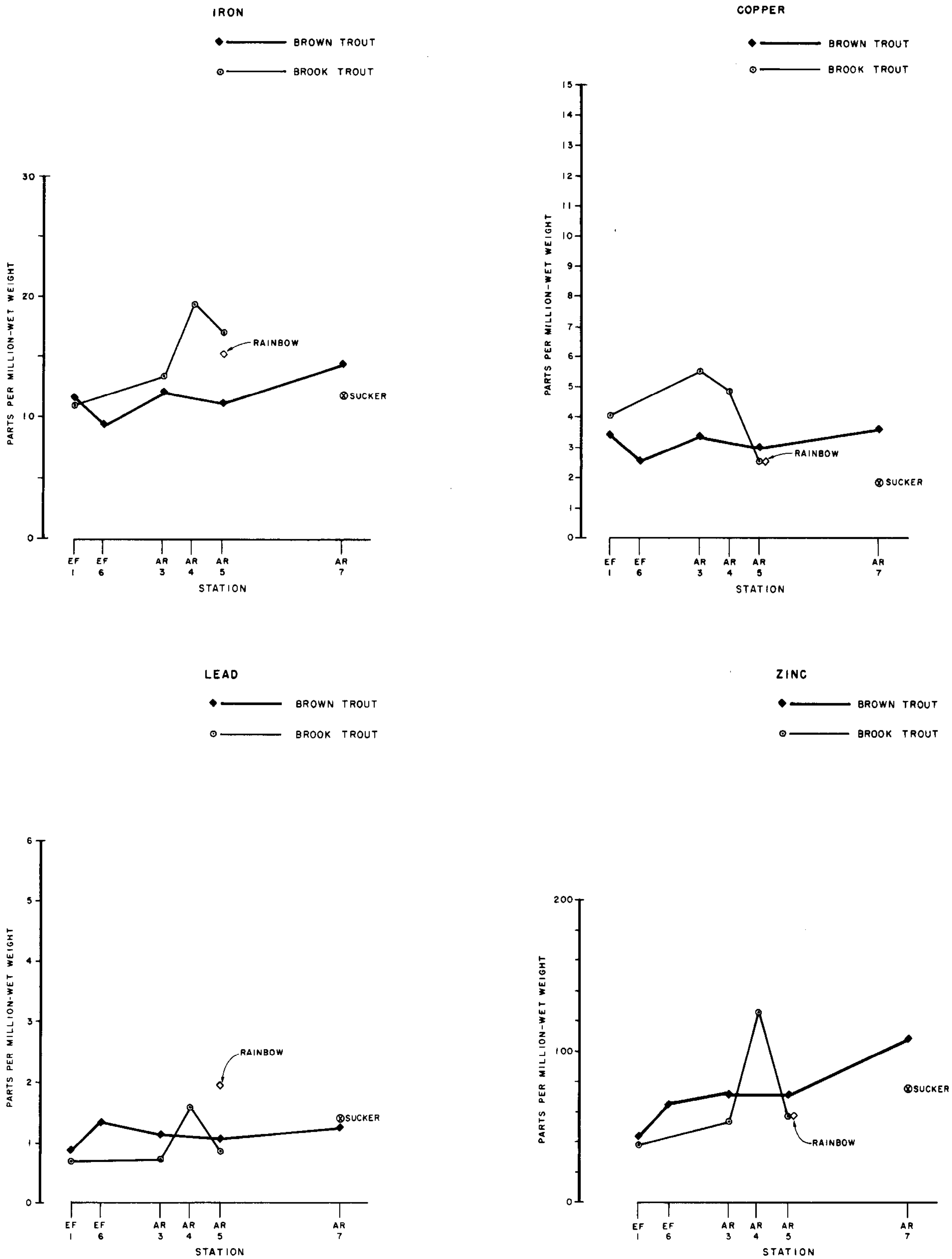


Figure 40. Iron, copper, lead, and zinc concentrations in fish samples (fillet plus skin)—September—1974.

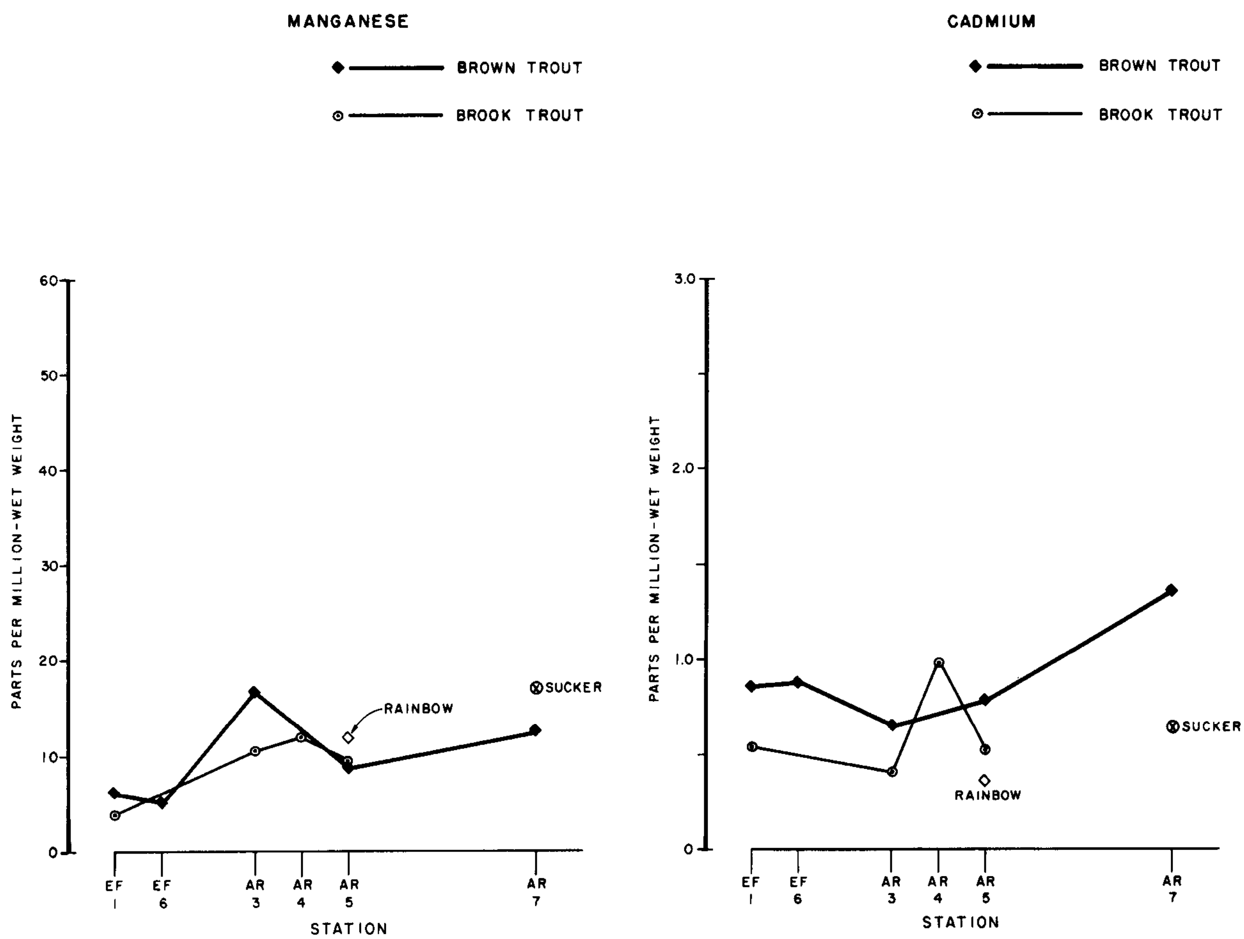


Figure 41. Manganese and cadmium concentrations in fish samples (fillet plus skin)—September—1974.

Table 16.—*Average heavy metal concentration in fish collected from the Upper Arkansas River, Colorado, September 18, 1974*

Species	Size (mm)	Average concentration (p/m, wet weight)					
		Fe	Cu	Pb	Zn	Mn	Cd
Salmo trutta (Brown trout)	90-240	12.04	3.17	1.15	72.4	10.08	0.67
Salmo gairdneri (Rainbow trout)	150-230	15.2	3.5	1.95	58.0	12.0	.35
Salvelinus fontinalis (Brook trout)	99-220	15.38	4.21	.98	66.5	9.0	.62
Catostomus commersoni (Sucker)	295	12.0	1.8	1.4	76.0	17.0	.64

found from less than 0.05 to 0.15 p/m cadmium in cod, whiting, plaice, herring, and mackerel. Holden and Topping (1972) found from 0.07 to 0.12 p/m cadmium in haddock, plaice, herring, mackerel, saithe, whiting, and dogfish. Concentrations of cadmium in fish from the Arkansas River were higher than all the above mentioned, again, probably as a result of excessive amounts of cadmium present in Arkansas River water.

The heavy metal concentration in fish collected from the Arkansas River, even though considered in all cases abnormally high, is not sufficiently high to render the fish unfit for human consumption.

CONCLUSIONS

The following is a summary of the conclusions based on the findings of this report:

1. There are three main areas of impact from heavy metal input:

    a. Leadville Drain and the sewage outflow from a trailer park.

    b. California Gulch outflow.

    c. Diffuse sources between AR-5 and AR-7.

2. The effect of the heavy metal input of Leadville Drain is not as extreme as the concentration of metals in the drain indicates; however, the sewage inflow, which is of about the same magnitude, may be a mitigating factor. Any treatment of one flow without regard to the other, or any increase in the drain's flow, should be viewed with caution.

3. Heavy metal input by California Gulch has a damaging effect on the river, but it is somewhat mitigated by the Lake Fork and Halfmoon Creek inflows which are now higher than they were historically. Any decrease in these mitigating flows could be expected to extend the effect of the gulch downstream. This conclusion is in agreement with the findings of Moran and Wentz (1974).

4. Although the diffuse sources of heavy metal input are not extremely damaging at present, a large decline in the Lake Fork and Halfmoon Creek inflows could be expected to compound the problem by allowing the effect of California Gulch to extend downstream.

5. The Lake Creek inflow counteracts the deleterious effect of the diffuse contaminant sources. Reduction of this flow would be expected to extend the heavy metal effect downstream.

6. Because of the lack of data on expected flows under project conditions, it is impossible to quantify the effects discussed. Operational hydrology should be added to these data at the first opportunity.

7. An alternative to maintaining the present mitigatory flows is to treat the heavy metal sources:

    a. Leadville Drain effluent, at present, is not the major problem; however, an increased drain flow and/or lack of sewage buffer could be expected to change this situation.

    b. Treatment of California Gulch effluent would remove the principal point source of pollution in the entire area, and should, therefore, be considered prior to treatment of the Leadville Drain effluent.

    c. The diffuse sources are difficult to deal with directly. To maintain present levels of quality in this area, without the dilution effect of Lake Fork and Halfmoon Creek, would necessitate eliminating California Gulch as a pollution source.

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APPENDIXES

Table A-1.—*Chemical analyses, East Fork and Leadville drain stations*

Parameter	Units	EF-1				EF-2				EF-3									EF-4			Sewage outlet	EF-5									EF-6		
		8-27-69	10-7-69	8-2-71	10-23-71	8-27-69	8-2-71	10-23-71	9-28-73	9-28-73	4-24-74	5-7-74	6-11-74	7-18-74	8-28-74	9-16-74	10-21-74	11-25-74	9-28-73	9-16-74	11-25-74	9-16-74	9-28-73	4-24-74	5-7-74	6-11-74	7-18-74	8-28-74	9-16-74	10-21-74	11-25-74	8-27-69	8-2-71	10-23-71
Conductivity	K x E^6 @ 25° C	176	195	191	203	740	707	743	769	198	205	165	161	151	184	212	275	213	760	782	825	784	300	373	214	193	201	260	307	375	337	247	212	297
pH	-	8	8.2	8.2	7.5	7.6	7.6	6.8	7.8	8	8.1	8.0	8.3	8.1	8.3	8.3	8.3	8.3	8	8.3	8.1	8.0	7.9	8.0	8.0	8.3	8.2	8.5	8.0	8.2	8.3	8.1	8.2	6.9
TDS	mg/l	132	156	96	164	652	544	624	592	148	124	156	120	100	100	172	176	196	572	612	668	580	200	340	200	156	180	188	204	296	300	168	132	252
Calcium	mg/l	22	23	19	24	103	90	92	101	24	23.80	18.8	16.4	16.0	23.2	23.0	24.2	26.8	94.4	97.2	128.0	98.2	36	46.0	24.4	22.0	20.2	32.0	35.4	44.0	43.2	29	24	35
Magnesium	mg/l	7.9	9.3	7.9	10	43	33	43	41	9.76	13.20	6.83	6.95	5.61	6.83	9.52	11.50	11.7	42	39.7	60.5	39.7	15.1	20.7	9.52	8.42	8.42	12.7	13.4	14.4	16.8	12	11	19
Sodium	mg/l	2.1	1.8	2.3	2.1	4.1	4.3	3.7	3.45	1.38	2.30	1.15	1.38	1.38	1.84	1.84	2.76	1.15	3.45	4.6	2.99	4.37	1.84	3.45	0.92	1.84	1.84	2.76	2.30	3.22	1.38	2.1	2.3	2.3
Potassium	mg/l	1.2	1.2	1.2	0.39	2	2	0.39	1.95	1.17	2.35	2.74	1.56	1.17	1.17	1.56	1.17	0.78	1.95	2.35	1.17	1.96	1.56	3.13	2.35	1.56	1.17	1.56	1.56	1.17	0.78	1.2	1.2	0.39
Carbonate	mg/l	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5.10	0	0	0	0	0	0
Bicarbonate	mg/l	85	96	65	99	105	130	150	141	79.3	98.8	58.6	64.7	63.4	84.8	90.3	114.0	109.0	142	140	180	126.0	96.4	98.8	63.4	73.2	67.1	84.8	102.0	126.0	119.0	103	65	150
Sulfate	mg/l	15	18	16	15	291	290	290	290	15.4	27.80	38.9	20.6	13.4	12.0	14.4	32.2	13.4	253	263	354	281.0	58.6	108.0	51.4	35.0	32.2	45.6	54.2	73.4	78.7	46	34	57
Chloride	mg/l	1.4	0	2.8	0	4.3	11	0	5.68	2.84	4.26	2.13	2.13	0.71	2.84	4.26	0.71	1.42	2.84	2.84	4.97	2.84	3.55	3.55	3.35	4.26	0.71	2.84	2.84	1.42	3.55	1.4	2.8	0
Nitrate	mg/l	0	0	0.62	0	1.2	1.2	0	3.72	2.48	0	0	0	0.62	0	0	0	0	2.48	0	0	1.24	2.48	0	0	0	2.48	0	0	0	0	0	0	0
Copper	mg/l	0	-	0	0	0	0	0	-	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	<0.05	<0.05	<0.05	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0	0	0
Iron	mg/l	<0.15	-	0	0	0.15	5	4.5	0.8*	0.2	0.29	0.80	0.10	0.23	0.2	0.79	<0.10	0.4	1.2	1.7	1.9	0.96	1.1	2.75	0.92	0.17	0.27	0.40	0.59	0.48	1.0	<0.15	0	0
Zinc	mg/l	0.03	-	0	0	1.3	6.6	6.8	7.2*	<0.05	<0.05	0.57	<0.05	<0.05	<0.05	0.02	<0.05	0.08	6.3	3.7	4.3	3.1	0.9	1.77	0.33	0.45	0.26	0.5	0.65	0.78	1.2	0.39	0.1	1.03
Manganese	mg/l	-	-	0	0	-	2.6	2.3	1.6*	<0.1	<0.05	0.10	<0.05	<0.05	<0.05	<0.05	<0.05	0.06	1.5	1.5	1.8	1.3	0.3	1.41	0.18	0.15	0.10	0.15	0.20	0.24	0.50	-	0	0.5
Lead	mg/l	0	-	-	-	0	-	-	-	-	<0.05	<0.05	<0.05	<0.2	<0.1	<0.2	<0.2	<0.2	-	<0.2	<0.2	<0.2	-	<0.05	<0.05	<0.05	<0.2	<0.1	<0.2	<0.2	<0.2	0	-	-

* These samples not acid treated.

Table A-2.—*Chemical analyses, Arkansas River stations*

Parameter	Units	AR-1								AR-2			AR-3													
		7-31-73	5-7-74	6-11-74	7-18-74	8-28-74	9-16-74	10-21-74	11-25-74	8-26-69	10-20-71	3-8-72	8-27-69	8-3-71	10-18-71	9-26-72	7-31-73	4-24-74	5-7-74	6-11-74	7-18-74	8-28-74	9-16-74	9-18-74	10-21-74	11-25-74
Conductivity	K x E^6 @ 25° C	130	102	170	130	229	260	291	309	201	240	309	208	177	217	242	143	213	104	124	142	223	254	256	282	240
pH	-	7.9	7.6	8.0	8.0	8.3	8.0	8.2	8.5	8.2	7.7	8	8	8	7.1	8	8.2	8	7.6	8.1	8.07	8.3	8.0	8.3	7.8	8.3
TDS	mg/l	112	120	144	176	168	172	220	200	172	184	264	148	120	120	164	126	124	120	68	88	144	156	164	240	200
Calcium	mg/l	14.8	10.20	16.4	14.0	29.0	29.2	30.8	42.8	24	27	37	27	21	29	29.6	12.8	18.8	11.4	13.4	16.2	28.4	29.2	28.0	29.8	31.2
Magnesium	mg/l	7.1	6.47	8.30	5.98	10.50	11.1	12.3	13.8	10	11	15	9.9	8.7	12	12.3	10.2	13.3	4.76	5.12	6.34	10.10	10.40	12.0	12.0	11.2
Sodium	mg/l	1.4	0.69	2.07	1.38	2.30	2.3	2.3	1.38	2.3	2.3	5.1	2.3	2.3	2.1	2.07	1.4	2.76	0.92	1.61	1.38	2.30	2.30	2.30	2.30	1.38
Potassium	mg/l	0.8	1.95	1.56	1.17	1.17	1.56	0.78	0.78	0.8	0.39	1.2	0.8	1.2	0.39	1.17	0.8	2.35	1.95	1.17	1.17	1.17	1.56	1.56	0.78	0.78
Carbonate	mg/l	0	0	0	0	0	0	0	1.50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bicarbonate	mg/l	47.6	31.7	53.1	47.6	87.8	89.1	105.0	112.0	93	88	89	86	72	88	84.8	63.4	63.4	31.7	42.7	54.9	92.1	86.0	84.8	101.0	93.9
Sulfate	mg/l	15.4	20.6	30.2	18.7	37.0	39.4	50.9	73.0	36	43	72	34	31	43	49.4	15.8	61.9	23.0	17.3	19.2	35.5	35.5	36.0	50.4	43.7
Chloride	mg/l	3.6	3.55	6.39	0.71	2.13	2.84	0.71	3.55	0.7	0	2.1	0.7	1.4	2.8	0.71	0.71	4.26	2.84	0.71	0.71	2.84	0.71	4.26	2.84	1.42
Nitrate	mg/l	-	0	0	0.62	0	0	0	0	0	0	0.62	0	0.62	0	0	-	0	0	0	0	0	0	0	0	0
Copper	mg/l	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0	0	-	0	0	0	0.1	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Iron	mg/l	0.39	0.65	0.15	0.26	0.2	0.28	<0.10	0.32	<0.15	0.8	-	<0.15	0	0.8	<1	0.22	0.40	0.77	0.15	0.90	0.2	0.29	0.72	<0.10	0.22
Zinc	mg/l	0.2	0.27	0.30	0.13	0.2	0.30	0.38	0.60	0.23	0.33	-	0.29	0.1	0.4	0.34	0.09	0.29	0.96	0.30	0.38	0.1	0.24	0.32	0.38	0.24
Manganese	mg/l	0.06	0.13	<0.05	0.056	0.07	0.08	0.09	0.15	-	0.17	-	-	0	0.17	0.1	0.05	0.13	0.12	<0.05	0.23	0.07	0.08	0.12	0.09	0.06
Lead	mg/l	-	<0.05	<0.05	<0.02	<0.1	<0.2	<0.2	<0.2	0	-	-	0	-	-	-	-	<0.05	<0.05	<0.05	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2

Table A-2.—*Chemical analyses, Arkansas River stations*—Continued

Parameter	Units	AR-4 10-20-71	AR-4 7-31-73	AR-4 4-24-74	AR-4 5-7-74	AR-4 6-11-74	AR-4 7-18-74	AR-4 8-28-74	AR-4 9-16-74	AR-4 10-21-74	AR-4 11-25-74
Conductivity	K x E^6 @ 25° C	333	182	299	146	129	187	304	355	357	332
pH	-	7.2	7.8	7.6	7.4	8.0	8.0	8.3	7.5	8.7	8.9
TDS	mg/l	288	138	236	124	88	148	236	236	212	304
Calcium	mg/l	37	19.6	31.8	14.4	14.6	20.2	37.2	37.0	38.8	46.8
Magnesium	mg/l	17	9.5	15.7	7.08	3.66	7.56	14.2	15.6	15.6	13.2
Sodium	mg/l	4.1	2.1	4.6	0.92	1.84	2.30	4.37	4.37	3.45	2.53
Potassium	mg/l	0.39	0.8	2.35	2.35	1.56	1.17	1.96	1.96	0.78	0.78
Carbonate	mg/l	0	0	0	0	0	0	0	0	1.5	6.3
Bicarbonate	mg/l	83	53.1	50.0	26.2	47.6	54.3	84.8	73.2	64.1	62.2
Sulfate	mg/l	99	39.8	104.0	42.7	17.8	37.4	75.8	88.3	98.9	111.0
Chloride	mg/l	0	3.6	5.68	3.55	-	0.71	2.84	2.84	1.42	-
Nitrate	mg/l	0	-	0	0	0	0	1.86	1.86	0	0
Copper	mg/l	0	0.06	0.06	<0.05	<0.05	0.05	<0.05	0.06	0.06	0.06
Iron	mg/l	3.75	1.9	2.55	1.32	0.25	0.945	3.0	4.4	3.5	5.0
Zinc	mg/l	4.75	5.9	3.71	1.58	1.80	1.35	2.4	3.4	3.8	4.6
Manganese	mg/l	2.16	0.05	2.19	0.47	0.33	0.53	1.76	2.0	1.7	2.3
Lead	mg/l	-	-	<0.05	<0.05	<0.05	0.2	<0.1	<0.2	<0.2	<0.2

Parameter	Units	AR-5 8-4-71	AR-5 9-27-72	AR-5 7-31-73	AR-5 4-24-74	AR-5 5-7-74	AR-5 6-11-74	AR-5 7-18-74	AR-5 8-28-74	AR-5 9-16-74	AR-5 9-18-74	AR-5 10-21-74	AR-5 11-25-74
Conductivity	K x E^6 @ 25° C	115	123	91	138	82	120	66	127	162	238	223	127
pH	-	7.5	7.6	7.2	7.4	7.4	8.0	7.67	8.3	7.4	8.1	8.1	7.8
TDS	mg/l	84	92	78	120	104	88	44	96	120	184	160	68
Calcium	mg/l	13	13.6	10.4	16.8	7.8	11.0	7.4	15.0	16.2	24.4	27.0	16.0
Magnesium	mg/l	5	5.73	3.9	3.78	4.15	5.12	2.68	4.64	5.49	9.15	6.59	5.25
Sodium	mg/l	3	2.07	1.8	3.45	0.69	2.30	1.84	2.30	3.22	4.37	3.22	1.61
Potassium	mg/l	1.2	1.17	0.8	1.95	0.78	1.17	1.17	1.17	1.56	1.56	0.78	0.78
Carbonate	mg/l	0	0	0	0	0	0	0	0	0	0	0	0
Bicarbonate	mg/l	38	37.2	37.2	34.2	21.3	41.5	23.2	47.0	42.7	63.4	70.2	42.10
Sulfate	mg/l	20	26.4	13.0	42.2	20.6	18.2	12.5	19.2	27.4	41.8	45.6	25.90
Chloride	mg/l	1.4	0.71	2.1	3.55	2.13	1.42	0.71	2.13	3.55	5.68	4.26	7.10
Nitrate	mg/l	0	0	-	0	0	0	0	0.62	0.62	0.62	0	0
Copper	mg/l	-	0	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.06	<0.05
Iron	mg/l	-	1	0.85	1.13	0.87	0.20	0.39	1.0	1.8	2.0	2.6	1.2
Zinc	mg/l	-	0.8	0.8	0.77	0.70	0.50	0.20	0.5	0.90	1.60	1.1	0.66
Manganese	mg/l	-	0.35	0.19	0.67	0.26	0.16	0.12	0.44	0.48	0.90	0.5	0.5
Lead	mg/l	-	-	-	<0.05	<0.05	<0.05	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2

Parameter	Units	AR-6 10-20-71	AR-6 5-7-74	AR-6 6-11-74	AR-6 7-18-74	AR-6 8-28-74	AR-6 9-16-74	AR-6 9-18-74	AR-6 10-21-74	AR-6 11-25-74
Conductivity	K x E^6 @ 25° C	180	91	119	74	133	167	244	235	103
pH	-	7.4	7.4	8.2	7.7	8.2	7.8	8.1	8.2	8.2
TDS	mg/l	152	112	128	100	104	112	196	184	64
Calcium	mg/l	19	9.0	10.8	8.2	15.6	17.2	25.4	26.8	14.0
Magnesium	mg/l	7.6	4.15	4.76	2.56	5.49	5.98	9.27	9.15	4.88
Sodium	mg/l	3	0.92	2.30	1.84	2.99	3.45	4.83	4.37	1.38
Potassium	mg/l	0.39	1.17	1.17	0.78	1.17	1.56	1.56	0.78	0.78
Carbonate	mg/l	0	0	0	0	0	0	0	0	0
Bicarbonate	mg/l	62	21.3	37.2	25.6	50.0	53.10	68.9	81.7	38.4
Sulfate	mg/l	31	24.5	17.8	12.5	21.6	26.40	39.8	50.9	20.6
Chloride	mg/l	0	1.42	1.42	0.71	2.84	2.13	6.39	4.26	1.42
Nitrate	mg/l	0	0	0	0.62	0	0	0	0	0
Copper	mg/l	0	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Iron	mg/l	0.8	1.20	0.20	0.43	0.9	1.1	1.2	0.80	0.50
Zinc	mg/l	0.56	1.10	0.50	0.21	0.5	0.55	1.3	0.70	0.28
Manganese	mg/l	0.34	0.34	0.14	0.13	0.36	0.32	0.70	0.35	0.20
Lead	mg/l	-	<0.05	<0.05	<0.2	<0.1	<0.2	<0.2	<0.20	<0.20

Table A-2.–*Chemical analyses, Arkansas River stations*–Continued

Parameter	Units	AR-9 5-7-74	AR-9 6-11-74	AR-9 7-18-74	AR-9 8-28-74	AR-9 9-16-74	AR-9 9-18-74	AR-9 10-21-74	AR-9 11-25-74
Conductivity	K x E^6 @ 25° C	96	139	81	144	176	239	234	126
pH	-	7.6	8.2	7.73	8.3	7.6	8.2	8.2	8.4
TDS	mg/l	116	88	140	124	112	176	200	88
Calcium	mg/l	10.0	13.4	9.2	17.2	18.8	25.2	30.8	17.6
Magnesium	mg/l	5.0	5.25	2.81	5.61	5.86	9.52	8.05	5.61
Sodium	mg/l	0.92	2.30	1.84	3.91	4.83	4.83	4.37	1.84
Potassium	mg/l	0.78	1.56	1.17	1.17	1.56	1.56	0.78	0.78
Carbonate	mg/l	0	0	0	0	0	0	0	0.60
Bicarbonate	mg/l	21.3	45.8	29.90	54.3	53.1	79.3	124.0	53.1
Sulfate	mg/l	23.0	19.2	12.5	21.6	26.4	32.2	23.5	13.9
Chloride	mg/l	2.13	1.42	0.71	1.42	2.13	4.26	3.55	3.55
Nitrate	mg/l	0.62	0	0.62	0	0	0	0	0
Copper	mg/l	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Iron	mg/l	1.38	0.20	0.38	0.7	0.97	0.90	0.40	0.64
Zinc	mg/l	0.89	0.50	0.20	0.5	0.55	1.0	0.23	0.32
Manganese	mg/l	0.32	0.14	0.11	0.32	0.27	0.48	0.12	0.20
Lead	mg/l	<0.05	<0.05	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2

Parameter	Units	AR-10 5-7-74	AR-10 6-11-74	AR-10 7-18-74	AR-10 8-28-74	AR-10 9-16-74	AR-10 9-18-74	AR-10 10-21-74	AR-10 11-25-74
Conductivity	K x E^6 @ 25° C	98	135	80	145	171	228	254	132
pH	-	7.6	8.2	7.78	8.2	8.0	8.2	8.0	8.6
TDS	mg/l	92	80	108	108	112	184	168	80
Calcium	mg/l	10.0	13.2	9.4	17.2	17.2	23.6	27.6	18.0
Magnesium	mg/l	4.64	5.12	2.93	5.49	6.34	9.15	9.03	5.25
Sodium	mg/l	0.92	2.76	1.84	3.45	3.91	5.29	4.60	2.07
Potassium	mg/l	0.78	1.56	0.78	1.17	1.56	1.56	0.78	0.78
Carbonate	mg/l	0	0	0	0	0	0	0	6.00
Bicarbonate	mg/l	31.7	54.3	27.50	56.10	53.1	71.4	85.4	42.7
Sulfate	mg/l	22.6	18.2	14.40	23.5	22.6	33.6	48.5	14.9
Chloride	mg/l	1.42	-	0.71	1.42	0.71	11.4	5.68	3.55
Nitrate	mg/l	0.62	0	0.62	0.62	1.24	0.62	0	0
Copper	mg/l	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Iron	mg/l	1.32	0.20	0.48	0.70	0.97	0.72	0.60	0.57
Zinc	mg/l	0.86	0.50	0.51	0.60	0.71	1.0	0.58	0.38
Manganese	mg/l	0.32	0.14	0.11	0.36	0.29	0.46	0.29	0.20
Lead	mg/l	<0.05	<0.05	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2

Parameter	Units	AR-7 8-3-71	AR-7 10-18-71	AR-7 9-26-72	AR-7 7-31-73	AR-7 4-24-74	AR-7 5-7-74	AR-7 6- -74	AR-7 7-18-74	AR-7 8-28-74	AR-7 9-16-74	AR-7 9-18-74	AR-7 10-21-74	AR-7 11-25-74
Conductivity	K x E^6 @ 25° C	132	152	175	112	158	95	129	81	144	170	222	243	117
pH	-	8	7.2	7.9	7.5	7.8	7.6	8.5	7.8	8.3	7.9	8.2	8.2	8.2
TDS	mg/l	56	116	160	96	132	104	84	164	104	112	168	200	76
Calcium	mg/l	15	18	32	13.6	18.0	11.6	12.2	9.2	18.0	17.2	23.8	27.6	20.40
Magnesium	mg/l	6.2	6.5	4.8	4.1	6.10	2.56	5.12	2.93	5.37	6.10	8.66	9.52	1.95
Sodium	mg/l	3	3.7	2.99	1.8	4.60	0.92	2.76	2.30	3.45	3.91	5.29	4.60	1.84
Potassium	mg/l	0.78	0.39	1.17	0.8	1.95	1.17	1.56	1.17	1.17	1.56	1.96	0.78	0.78
Carbonate	mg/l	0	0	0	0	0	0	4.2	0	0	0	0	0	0
Bicarbonate	mg/l	49	62	81.7	37.2	47.6	21.3	34.8	29.90	58.60	63.4	77.5	84.8	46.40
Sulfate	mg/l	17	31	16.8	14.4	45.1	20.6	25.0	13.0	19.7	23.5	31.7	49.9	16.80
Chloride	mg/l	2.1	2.8	4.26	4.3	2.84	2.84	-	0.71	1.42	0.71	4.26	4.26	2.13
Nitrate	mg/l	0.62	0	0	-	0	0	0	0.62	0	0	0.62	0	0
Copper	mg/l	0	0	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Iron	mg/l	0	0.8	-	0.82	0.91	1.14	0.20	0.37	0.6	1.0	0.61	0.48	0.88
Zinc	mg/l	0.2	0.4	-	0.6	0.77	0.71	0.50	0.20	0.5	0.60	0.92	0.64	0.46
Manganese	mg/l	0	0.34	-	0.15	0.50	0.26	0.14	0.097	0.32	0.29	0.41	0.29	0.20
Lead	mg/l	-	-	-	-	<0.05	<0.05	<0.05	<0.20	<0.1	<0.2	<0.2	<0.2	<0.2

Table A-2.—*Chemical analyses, Arkansas River stations*—Continued

Parameter	Units	AR-8										
		8-3-71	10-20-71	7-31-73	5-7-74	6-11-74	7-18-74	8-28-74	9-16-74	9-18-74	10-21-74	11-25-74
Conductivity	K x E^6 @ 25° C	116	159	105	81	114	72	136	161	147	212	109
pH	-	7.7	7.3	7.5	7.6	8.0	7.72	8.3	8.0	8.0	8.1	8.4
TDS	mg/l	104	164	148	68	64	144	88	96	124	152	76
Calcium	mg/l	17	17	11.2	9.2	11.4	8.8	17.2	16.4	16.6	22.4	12.4
Magnesium	mg/l	3.5	5.6	4.5	2.93	3.42	2.44	4.88	5.86	4.88	8.42	6.22
Sodium	mg/l	2.8	3	1.8	0.92	2.30	1.38	3.22	3.45	2.76	4.14	1.38
Potassium	mg/l	0.78	0.39	0.4	0.78	1.17	0.78	1.17	1.56	1.56	0.78	0.78
Carbonate	mg/l	0	0	0	0	0	0	0	0	0	0	1.20
Bicarbonate	mg/l	40	56	31.7	21.3	32.9	25.60	53.1	47.6	47.6	70.8	39.7
Sulfate	mg/l	18	24	19.7	20.20	21.6	13.0	19.7	22.6	21.1	43.7	18.7
Chloride	mg/l	2.1	0	5.7	3.55	0.71	0.71	1.42	0.71	4.26	4.26	4.26
Nitrate	mg/l	0.62	0	-	0	0	0.62	0	0	0	0	0
Copper	mg/l	0	0	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Iron	mg/l	0	0.8	0.39	0.65	0.15	0.23	0.6	0.75	0.40	0.20	0.40
Zinc	mg/l	0.2	0.4	0.13	0.50	0.40	0.13	0.5	0.50	0.41	0.49	0.38
Manganese	mg/l	0	0.17	<0.05	0.12	0.05	0.05	0.32	0.23	0.28	0.20	0.20
Lead	mg/l	-	-	-	<0.05	<0.05	<0.02	<0.1	<0.2	<0.2	<0.2	<0.2

Parameter	Units	Arkansas River at Granite																				
		10-4-67	11-15-67	12-6-67	1-10-68	2-8-68	3-4-68	4-8-68	5-6-68	6-6-68	7-3-68	8-8-68	9-5-68	10-15-68	11-6-68	12-5-68	1-8-69	2-10-69	3-17-69	4-9-69	5-22-69	6-19-69
Conductivity	K x E^6 @ 25° C	171	186	226	221	183	175	181	100	88	85	123	142	158	175	186	215	220	201	185	93	131
pH	-	7.6	7.4	7.3	7.5	7.3	7.3	7.5	7.1	7.1	7.4	7.3	7.2	7.2	7.1	7.1	7.5	7.6	7.5	7.4	7.2	7.2
TDS	mg/l	102	121	137	136	116	120	113	65	60	58	68	77	93	120	115	135	145	128	127	69	76
Calcium	mg/l	19	20	28	26	22	20	21	12	10	10	12	11	15	20	21	23	24	22	20	11	15
Magnesium	mg/l	7.0	8.3	9.2	10	7.3	6.3	6.3	3.4	3.4	2.9	7.5	9.7	90	7.1	7.8	8.8	9.2	8.0	7.3	3.3	5.8
Sodium	mg/l	3.7	4.2	5.3	5.0	4.0	4.3	4.1	1.9	1.6	1.7	1.9	2.6	3.3	3.8	4.2	4.8	4.4	4.7	4.7	2.3	2.4
Potassium	mg/l	1.0	1.0	1.1	1.1	0.8	0.9	0.9	0.6	0.6	0.4	0.7	0.7	0.8	1.0	1.0	1.0	1.0	2.5	1.6	0.8	0.8
Carbonate	mg/l	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bicarbonate	mg/l	68	68	84	86	66	63	60	32	26	31	54	60	62	64	66	78	81	71	64	33	53
Sulfate	mg/l	28	33	38	41	34	34	34	20	20	14	17	21	27	27	37	39	43	33	32	16	19
Chloride	mg/l	2.1	2.9	3.5	2.8	2.8	1.5	3.0	1.7	1.7	1.7	1.2	1.3	1.8	2.5	3.0	3.1	3.0	3.0	3.0	0.8	2.0
Nitrate	mg/l	0	0.1	1.3	1.0	1.1	0.3	0.3	0.2	0.3	0.2	0.2	0.2	0.1	0	0.1	2.3	1.1	1.3	1.5	0.6	0.6
Copper	mg/l	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Iron	mg/l	0.04	0.02	0.05	0	0.02	0.03	0.07	0.10	0.11	0.06	0.11	0.09	0.09	0.05	0.06	0.05	0.03	0.06	0.130	0.08	0.240
Zinc	mg/l	0.21	0.23	0.58	0.64	0.43	0.39	0.42	0.19	0.38	0.17	0.19	0.26	0.270	0.540	0.470	0.810	0.820	0.420	0.220	0.390	0.370
Manganese	mg/l	0.18	0.28	0.34	0.32	0.24	0.22	0.21	0.06	0.11	0.07	0.11	0.15	0.160	0.340	0.320	0.350	0.310	0.280	0.140	0.120	0.130
Lead	mg/l	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table A-2.—*Chemical analyses—Arkansas River stations*—Continued

Parameter	Units	Arkansas River at Canon City											
		10-31-72	11-28-72	12-29-72	1-29-73	3-9-73	4-4-73	5-10-73	6-19-73	7-19-73	8-29-73	10-15-73	11-20-73
Conductivity	K x E^6 @ 25° C	306	278	310	324	342	350	340	206	214	159	344	360
pH	-	7.1	8.0	8.4	8.2	8.1	8.1	8.2	8.2	8.2	8.0	8.5	8.5
TDS	mg/l	183	179	190	199	201	207	220	123	133	87	213	217
Calcium	mg/l	37	36	37	38	40	40	43	25	29	26	43	43
Magnesium	mg/l	8.7	9.1	9.2	9.6	9.8	11	12	6.4	6.9	4.0	10.0	11.0
Sodium	mg/l	12	12	13	14	14	15	16	6.5	6.4	5.6	14.0	15.0
Potassium	mg/l	2.0	1.8	1.8	2.0	1.9	2.5	2.4	1.4	1.0	1.0	2.2	2.1
Carbonate	mg/l	0	0	0	0	0	0	0	0	0	0	5	1
Bicarbonate	mg/l	141	132	145	156	163	168	181	100	114	68	151	160
Sulfate	mg/l	33	33	34	35	32	33	34	20	19	5.6	43.0	42.0
Chloride	mg/l	7.3	7.0	8.0	8.1	9.0	9.3	8.5	2.9	3.0	2.6	7.6	9.2
Nitrate	mg/l	0.17	0.23	0.31	0.15	0.15	0.04	0.04	0.10	0.08	0.09	0.06	0.18
Copper	mg/l												
Iron	mg/l	0.04	0.78	0.02	0.03	0.02	0.03	0.03	0.08	0.04	0	0.01	0.01
Zinc	mg/l												
Manganese	mg/l	0.01	0.02	0	0	0	0.04	0.021	0.01	0.01	0.016	0.017	0.010
Lead	mg/l												

Table A-3.—*Chemical analyses, California Gulch and Yak Tunnel stations*

Parameter	Units	CG-1		CG-2	CG-3		CG-4					CG-5								Iowa Gulch
		8-27-69	8-3-71	10-18-71	8-27-69	8-3-71	8-27-69	10-7-69	8-3-71	10-18-71	3-8-72	8-27-69	8-3-71	10-20-71	3-6-72	9-27-72	4-24-74	9-16-74	10-25-74	6-11-74
Conductivity	K x E^6 @ 25° C	924	748	1,690	1,113	1,790	1,191	1,101	1,930	1,090	857	912	1,320	1,020	1,050	1,040	804	965	996	514
pH	-	3.4	3.4	3.3	3.8	3	3.7	5.7	2.9	4.8	7.2	7	3.7	6.8	5.6	6.1	6.6	7.2	6.8	8.6
TDS	mg/l	972	624	1,480	1,116	1,470	1,240	956	1,600	1,060	716	824	1,200	872	772	976	788	784	884	380
Calcium	mg/l	107	48	170	140	150	182	126	160	130	110	99	140	100	120	100	92	93.8	126	59.2
Magnesium	mg/l	20	18	72	53	71	48	81	82	56	51	63	61	52	75	68.3	56.10	54.4	68.3	22.7
Sodium	mg/l	2.1	2.3	5.5	4.8	6.2	5.1	4.6	6.2	3.9	12	13	10	25	16	14.9	11.00	16.6	9.43	3.45
Potassium	mg/l	1.2	1.2	0.78	3.1	3.5	3.1	2.7	3.1	0.39	3.1	4.3	3.5	11	5.1	4.3	4.30	5.08	2.35	2.35
Carbonate	mg/l	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10.50
Bicarbonate	mg/l	0	0	0	0	0	0	5.5	0	0	32	54	0	59	1.2	7.32	7.32	34.8	37.8	154
Sulfate	mg/l	552	390	960	643	950	701	629	1,100	660	430	454	770	440	540	586	410.0	447	466	89.3
Chloride	mg/l	7.1	2.1	4.3	2.8	11	1.4	2.1	7.1	5.7	9.9	8.5	11	7.1	11	13.5	5.68	12.8	6.39	6.34
Nitrate	mg/l	0	0	0	0.6	1.9	1.2	0	0.62	0	0.62	0.6	0.62	0	8.7	0	0	0	13.6	1.86
Copper	mg/l	1.3	0.9	2.1	1.36	3.8	0.89	-	4.8	0.85	1.6	0	2.1	0	2.0	0.84	0.80	0.42	0.39	<0.05
Iron	mg/l	0.75	2.3	63.5	0.9	66	0.3	-	72	37.5	50	0.55	30	23	59.3	33.6	21.80	31.0	24.8	<0.05
Zinc	mg/l	42	22.6	80	48	80	48.8	-	97.6	0.4	43	30	61.2	33	35	45.5	36.0	29.0	32.4	<0.05
Manganese	mg/l	-	11.8	28.4	-	34	-	-	39.2	18.5	13.5	-	26	13.5	15	18.8	17.50	18.5	17.0	<0.05
Lead	mg/l	0.6	-	-	0.9	-	0	-	-	-	-	0	-	-	-	-	3.05	<0.2	1.1	<0.05

APPENDIX A

Water Chemistry

Table A-4.—*Chemical analyses, Lake Fork stations*

Parameter	Units	LF-1					LF-2
		8-26-69	10-7-69	8-2-71	10-23-71	7-73-73	10-20-71
Conductivity	K x E6 at 25° C	33.5	97	31	32	28	73
pH	–	7.1	7.2	7.4	6.8	6.5	7.3
TDS	mg/1	20	70	36	64	46	88
Calcium	mg/1	4.6	8.6	4.2	3.8	2.2	7.2
Magnesium	mg/1	.7	3.7	1.5	.85	2.1	2.4
Sodium	mg/1	1.2	1.6	1.4	.92	.92	2.3
Potassium	mg/1	.8	.8	.78	.39	1.2	.39
Carbonate	mg/1	0	0	0	0	0	0
Bicarbonate	mg/1	19	15	21	11	10.4	29
Sulfate	mg/1	5.3	2.6	5.8	7.7	2.9	10
Chloride	mg/1	2.8	0	2.1	0	2.8	0
Nitrate	mg/1	0	0	0	0	–	0
Copper	mg/1	0	–	0	0	<.05	0
Iron	mg/1	<.15	–	0	.8	.14	0
Zinc	mg/1	.02	–	0	0	<.04	.4
Manganese	mg/1	–	–	0	0	<.05	.17
Lead	mg/1	0	–	–	–	–	–

Table A-5.—*Chemical analyses, Lake Creek stations*

Parameter	Units	LC-1					LC-3				
		8-26-69	8-3-71	10-18-71	3-8-72	8-1-73	8-26-69	10-7-69	8-3-71	10-20-71	9-25-72
Conductivity	K x E^6 at 25° C	95.7	74	113	146	64	67	74	64	76	83
pH	–	7.5	7.6	6.5	7.8	7.2	7.3	7.5	7.7	7.1	7.7
TDS	mg/1	72	64	120	80	84	60	52	76	52	64
Calcium	mg/1	14	11	16	20	9.2	10	10	9.2	9.6	12.8
Magnesium	mg/1	2	1.6	2.2	3.9	.73	1.1	1.5	1.5	1.5	1.4
Sodium	mg/1	1.6	1.4	1.8	4.4	1.4	1.4	1.2	1.4	1.4	1.38
Potassium	mg/1	.4	.78	.39	1.2	.4	.8	.8	.78	.39	.78
Carbonate	mg/1	0	0	0	0	0	0	0	0	0	0
Bicarbonate	mg/1	29	23	29	33	21.4	23	27	23	27	22.6
Sulfate	mg/1	26	19	29	42	11	12	11	15	12	15.4
Chloride	mg/1	.7	.7	1.4	1.4	2.8	1.4	0	.71	0	.71
Nitrate	mg/1	.6	0	0	.62	–	0	0	0	0	0
Copper	mg/1	0	0	0	–	<.05	0	–	0	0	0
Iron	mg/1	<.15	0	.8	–	.33	.2	–	0	0	<1.0
Zinc	mg/1	0	0	.4	–	<.04	0	–	0	0	.06
Manganese	mg/1	–	–	0	–	<.05	–	–	0	0	.1
Lead	mg/1	0	0	–	–	–	0	–	–	–	–

APPENDIX B

Streamflow

Table B-1.—*Estimated daily discharges in ft^3/s at sampling stations of upper Arkansas River, Colorado*

Day	May	June	July	Aug	Sept	Oct
			Station: EF-3			
1	33	97	48	21	8	6
2	40	93	45	20	8	6
3	37	90	42	21	7	6
4	40	81	36	20	5	6
5	38	89	37	19	6	6
6	48	82	36	17	6	5
7	54	76	36	16	6	5
8	61	67	35	16	6	5
9	82	55	33	15	6	5
10	81	54	33	23	6	5
11	76	53	31	19	6	4
12	77	57	28	15	6	4
13	87	77	28	15	6	4
14	68	87	28	13	6	4
15	55	98	28	13	7	4
16	74	100	28	11	8	4
17	96	100	31	11	7	4
18	88	98	32	10	7	4
19	115	101	31	10	6	4
20	85	90	29	12	6	4
21	67	93	36	10	6	4
22	63	86	39	11	6	4
23	71	82	37	10	6	4
24	73	78	29	10	6	4
25	77	73	28	10	6	4
26	94	67	26	9	6	4
27	119	61	25	9	6	4
28	121	60	24	8	6	4
29	137	55	25	8	6	4
30	139	51	24	8	6	4
31	129	-	23	8	-	4

May-Sept: Native flow Arkansas River near Leadville x D.A.R. (0.39) + Columbine Ditch imports. Oct: Sept avg. reduced by Historical Ratio Oct/Sept (0.74) Arkansas River near Leadville

Table B-1.—*Estimated daily discharges in ft^3/s at sampling stations of upper Arkansas River, Colorado*—Continued

Day	May	June	July	Aug	Sept	Oct
Station: AR-4						
1	99	279	137	62	25	19
2	115	262	127	63	25	19
3	108	255	121	68	23	18
4	117	233	111	63	19	18
5	117	256	111	64	22	17
6	146	254	107	60	21	17
7	162	228	108	50	21	17
8	180	203	106	50	21	17
9	234	169	101	51	20	17
10	247	166	101	73	20	17
11	233	162	95	59	20	17
12	237	170	88	49	21	17
13	263	206	88	47	21	16
14	212	234	84	42	22	16
15	176	265	87	42	23	16
16	213	269	85	39	26	16
17	276	270	93	36	25	16
18	259	265	98	33	23	16
19	329	273	96	30	22	16
20	252	253	87	38	21	15
21	205	247	106	34	21	15
22	191	233	116	32	22	15
23	198	223	109	30	21	15
24	209	213	91	30	22	15
25	218	196	87	31	22	15
26	264	182	78	30	22	15
27	330	176	78	29	22	14
28	338	169	75	28	22	14
29	384	158	78	27	22	14
30	383	146	77	26	22	14
31	342	-	67	25	-	14

Sampling Point AR-3 plus California Gulch estimated on basis of spot measurements.

Table B-1.—*Estimated daily discharges in ft^3/s at sampling stations of upper Arkansas River, Colorado*—Continued

Day	May	June	July	Aug	Sept	Oct
			Station:	EF-5		
1	36	100	51	24	11	9
2	43	96	48	23	11	9
3	40	93	45	24	10	9
4	43	84	39	23	8	9
5	41	92	40	22	9	9
6	51	85	39	20	9	8
7	57	79	39	19	9	8
8	64	70	38	19	9	8
9	85	58	36	18	9	8
10	84	57	36	26	9	8
11	79	56	34	22	9	7
12	80	60	31	18	9	7
13	90	80	31	18	9	7
14	71	90	31	16	9	7
15	58	101	31	16	10	7
16	77	103	31	14	11	7
17	99	103	34	14	10	7
18	91	101	35	13	10	7
19	118	104	34	13	9	7
20	88	93	32	15	9	7
21	70	96	39	13	9	7
22	66	89	42	14	9	7
23	74	85	40	13	9	7
24	76	81	32	10	9	7
25	80	76	31	10	9	7
26	97	70	29	9	9	7
27	122	64	28	9	9	7
28	124	63	27	8	9	7
29	140	58	28	8	9	7
30	142	54	27	8	9	7
31	132	-	26	8	-	7

EF-1 plus Leadville Drain

Table B-1.—*Estimated daily discharges in ft^3/s at sampling stations of upper Arkansas River, Colorado*—Continued

Day	May	June	July	Aug	Sept	Oct
			Station:	AR-1		
1	88	266	127	54	20	15
2	104	250	117	54	20	15
3	97	242	111	58	18	14
4	104	220	102	54	14	14
5	106	242	98	52	15	13
6	134	238	95	46	15	13
7	150	212	95	43	15	13
8	168	186	93	42	15	13
9	223	155	88	43	15	13
10	234	152	88	62	15	13
11	220	150	85	51	15	13
12	223	160	77	41	16	13
13	250	195	77	39	16	12
14	198	223	74	35	17	12
15	165	254	76	35	18	12
16	202	258	74	32	20	12
17	266	258	83	29	19	12
18	246	254	86	27	18	12
19	315	262	85	27	17	12
20	238	242	77	32	16	11
21	192	238	95	28	16	11
22	180	223	104	26	17	11
23	186	212	97	25	16	11
24	198	202	80	25	17	11
25	209	186	76	26	17	11
26	254	171	68	24	17	11
27	320	165	67	23	17	10
28	325	158	64	22	17	10
29	370	145	67	22	17	10
30	370	134	65	21	17	10
31	330	-	58	20	-	10

May-Sept: 1974 Advanced records Arkansas River near Leadville; Oct: Computed from historical Oct/Sept ratio (0.74)

Table B-1.—*Estimated daily discharges in ft^3/s at sampling stations of upper Arkansas River, Colorado*—Continued

Day	May	June	July	Aug	Sept	Oct
			Station:	AR-3		
1	93	271	132	59	22	17
2	109	254	122	60	22	17
3	102	247	116	65	20	16
4	111	225	106	60	16	16
5	111	248	106	61	19	15
6	140	246	102	57	18	15
7	156	220	103	47	18	15
8	174	195	101	47	18	15
9	228	161	96	48	17	15
10	241	158	96	70	17	15
11	227	154	90	56	17	15
12	231	162	83	46	18	15
13	257	198	83	44	18	14
14	206	226	79	39	19	14
15	170	257	82	39	20	14
16	207	261	80	36	23	14
17	270	262	88	33	22	14
18	253	257	93	30	20	14
19	323	265	91	27	19	14
20	246	245	82	35	18	13
21	199	239	101	31	18	13
22	185	225	110	29	19	13
23	192	215	104	27	18	13
24	203	205	86	27	19	13
25	212	188	82	28	19	13
26	258	174	73	27	19	13
27	324	168	73	26	19	12
28	332	161	70	25	19	12
29	378	150	73	24	19	12
30	377	138	72	23	19	12
31	336	-	62	22	-	12

Sampling Point AR-1 plus 0.05 (Arkansas At Granite - Lake Creek below Twin Lakes - Halfmoon Creek near Malta - Lake Fork below Sugar Loaf Dam - Arkansas near Leadville)

Table B-1.—*Estimated daily discharges in ft³/s at sampling stations of upper Arkansas River, Colorado*—Continued

Day	May	June	July	Aug	Sept	Oct
			Station:	AR-5		
1	393	801	484	508	235	46
2	431	771	544	520	247	50
3	435	766	405	527	245	50
4	356	708	376	510	237	51
5	343	719	457	464	145	49
6	384	710	503	371	100	50
7	450	676	492	499	99	51
8	495	591	483	499	97	41
9	636	481	483	505	93	33
10	708	418	483	485	94	31
11	658	378	464	504	93	33
12	635	431	513	494	94	33
13	638	502	520	487	98	32
14	531	535	522	482	99	31
15	499	626	518	480	103	37
16	622	662	515	474	99	32
17	735	678	515	470	66	32
18	778	662	470	462	68	33
19	862	688	570	328	77	32
20	758	670	544	219	65	32
21	675	737	562	217	68	39
22	661	759	573	205	69	36
23	662	720	548	182	68	36
24	685	679	499	184	68	42
25	694	644	495	181	67	44
26	771	647	463	159	66	44
27	871	661	461	129	63	43
28	895	655	457	127	67	43
29	936	564	461	125	56	43
30	934	503	480	125	53	43
31	878	-	498	124	-	43

Flow at Sampling Point AR-6 less 0.12 times flow from intervening area between existing gages.

Table B-1.—*Estimated daily discharges in ft^3/s at sampling stations of upper Arkansas River, Colorado*—Continued

Day	May	June	July	Aug	Sept	Oct
			Station:	AR-6		
1	406	814	495	519	240	50
2	443	780	557	534	252	54
3	448	778	416	543	250	54
4	372	720	386	524	242	55
5	356	734	477	485	154	53
6	398	730	521	397	108	54
7	465	694	512	510	107	55
8	508	614	502	510	105	45
9	647	497	501	517	99	37
10	724	432	503	505	99	35
11	675	388	477	516	97	37
12	654	436	527	505	98	37
13	656	509	534	498	103	36
14	552	543	534	492	104	35
15	510	633	532	490	109	41
16	635	671	529	484	106	36
17	745	687	528	479	73	36
18	796	669	486	470	72	37
19	883	695	585	329	83	36
20	778	676	556	225	70	36
21	693	740	577	223	73	43
22	674	765	589	211	74	40
23	676	727	565	187	73	40
24	697	685	514	189	73	46
25	702	649	509	186	72	48
26	782	654	476	166	71	48
27	882	667	474	136	69	47
28	911	663	471	133	72	47
29	954	576	477	130	61	47
30	950	513	496	130	58	47
31	893	-	409	129	-	47

Flow at Sampling Point AR-9 less 0.22 times flow from intervening area between existing gages.

Table B-1.—*Estimated daily discharges in ft^3/s at sampling stations of upper Arkansas River, Colorado*—Continued

Day	May	June	July	Aug	Sept	Oct
			Station:	AR-9		
1	429	838	516	539	250	58
2	464	797	581	559	262	62
3	471	799	437	573	260	62
4	401	743	405	549	252	63
5	380	762	514	523	170	61
6	423	767	554	444	123	62
7	492	727	548	529	121	63
8	533	655	537	530	119	53
9	668	526	535	540	109	45
10	753	458	540	541	108	43
11	706	406	501	538	105	45
12	689	446	553	525	105	45
13	689	522	559	518	113	44
14	590	557	557	511	114	43
15	531	646	558	509	120	49
16	659	685	555	502	119	44
17	763	703	552	496	86	44
18	829	682	515	484	80	45
19	921	707	613	331	94	44
20	815	688	579	237	79	44
21	725	745	604	235	82	51
22	698	775	618	223	83	48
23	702	741	596	197	82	48
24	719	696	541	198	82	54
25	717	658	535	195	81	56
26	802	666	499	179	81	56
27	900	679	499	148	80	55
28	941	677	496	144	82	55
29	987	599	505	140	70	55
30	979	532	525	139	68	55
31	920	-	529	138	-	55

Flow at Sampling Point AR-10 less 0.13 flow from intervening area between existing gages.

Table B-1.—*Estimated daily discharges in ft³/s at sampling stations of upper Arkansas River, Colorado*—Continued

Day	May	June	July	Aug	Sept	Oct
			Station: AR-10			
1	443	852	528	551	256	63
2	477	807	495	574	268	67
3	485	811	449	591	266	67
4	418	757	416	564	258	68
5	394	779	536	545	179	66
6	438	789	563	472	132	67
7	508	747	569	540	129	68
8	548	679	558	542	127	58
9	680	543	555	553	115	50
10	770	473	562	563	113	48
11	724	417	515	551	110	50
12	710	452	568	537	109	50
13	708	530	574	530	119	49
14	613	565	570	522	120	48
15	543	654	574	520	126	54
16	673	693	570	512	127	49
17	774	713	566	506	94	49
18	848	690	532	492	85	50
19	944	714	630	332	100	49
20	837	695	592	244	84	49
21	744	748	620	242	87	56
22	712	781	635	230	88	53
23	718	749	614	203	88	53
24	732	703	557	203	88	59
25	726	663	551	200	86	61
26	814	673	513	187	87	61
27	911	686	513	155	86	60
28	959	685	511	151	88	60
29	1007	612	522	146	75	60
30	996	543	542	144	74	60
31	936	-	541	144	-	60

Flow at Sampling Point AR-7 less 0.08 flow from intervening area between existing gages.

Table B-1.—*Estimated daily discharges in ft³/s at sampling stations of upper Arkansas River, Colorado*—Continued

Day	May	June	July	Aug	Sept	Oct
			Station: AR-7			
1	451	861	536	558	260	69
2	485	813	504	583	272	70
3	493	819	457	602	270	70
4	429	765	423	573	262	71
5	403	789	550	559	185	69
6	447	802	575	489	137	70
7	518	759	582	547	134	71
8	557	694	571	549	132	61
9	688	553	567	561	119	53
10	781	483	576	576	116	51
11	735	424	524	559	113	53
12	723	456	577	544	112	53
13	720	535	583	537	123	52
14	627	570	578	529	124	51
15	551	659	584	527	130	57
16	682	698	580	518	132	52
17	781	719	575	512	99	52
18	860	695	643	497	88	53
19	958	718	640	337	104	52
20	841	699	600	248	87	52
21	756	750	630	246	90	59
22	721	785	645	234	91	56
23	738	754	625	207	91	56
24	740	707	567	204	91	62
25	732	666	561	203	89	64
26	821	677	521	192	91	64
27	917	690	522	159	90	63
28	970	690	520	155	82	63
29	1019	620	532	150	78	63
30	1007	550	553	147	80	63
31	946	-	548	147	-	63

Flow at Sampling Point AR-8 less flow of Lake Creek below Twin Lakes.

Table B-1.—*Estimated daily discharges in ft^3/s at sampling stations of upper Arkansas River, Colorado*—Continued

Day	May	June	July	Aug	Sept	Oct
			Station: AR-8			
1	872	1347	739	847	556	101
2	900	1221	683	889	701	102
3	935	1148	625	905	693	102
4	896	1068	578	862	680	103
5	917	1095	789	828	557	108
6	1026	1110	1012	751	558	110
7	1115	1072	990	811	544	108
8	1175	1007	1021	820	359	101
9	1309	806	1042	828	176	92
10	1474	709	1040	838	174	91
11	1533	650	1097	819	183	92
12	1531	682	1396	802	186	84
13	1522	761	1446	793	163	84
14	1419	850	1448	785	138	82
15	1309	1043	1426	776	144	89
16	1337	1132	1416	758	148	83
17	1430	1161	1417	750	148	84
18	1602	1143	1404	733	164	84
19	1739	1163	1375	519	146	84
20	1570	1144	1348	294	120	83
21	1122	1217	1385	289	122	91
22	953	1294	1374	268	122	87
23	961	1223	1193	236	122	88
24	963	1144	1015	233	122	94
25	958	1095	1006	233	120	96
26	1049	1103	971	222	122	95
27	1350	1124	881	189	121	95
28	1564	1092	835	184	113	93
29	1622	954	861	179	109	95
30	1604	812	887	177	107	94
31	1475	-	865	168	-	95

May-Sept: 1974 advanced records Arkansas River at Granite - 0.12 (Arkansas River at Granite - Lake Creek below Twin Lakes - Halfmoon Creek near Malta - Lake Fork below Sugar Loaf - Arkansas River near Leadville; this is the intervening area between existing gages referred elsewhere in these tabulations)
October: (0.88 x Estimated intervening area between existing gages)(see note above) + Estimated flow Lake Creek below Twin Lakes + 1964 Halfmoon near Malta + Estimated AR-1 + Sugar Loaf releases from daily reports.

APPENDIX C

1974 Invertebrate Data

Table C-1.—*Arkansas River Invertebrate Summary, June 1974*

Taxon	Tolerance class	Sampling stations								
		EF-3	AR-1	AR-3	AR-4	AR-5	AR-9	AR-10	AR-7	AR-8
Oligochaeta										
Enchytraeidae										
Genus 1[2]	2					2				
Ephemeroptera										
Baetidae				[1]9						
Baetis	2	8	5	2			4		3	1
Ephemerella	1	1				7				
Heptageniidae		[1]2		[1]4						
Plecoptera		[1]4		[1]3						
Pteronarcidae										
Pteronarcella	1	1					4			
Nemouridae										
Nemoura	1	67	2	3					1	
Perlodidae										
Archynopteryx	1	5								
Isoperla	1		3				13	2	4	
Chloroperlidae										
Alloperla	1	6	1	1			3	8	4	
Trichoptera										
Hydropsychidae										
Arctopsyche	1					1				
Rhyacophilidae										
Rhyacophila	1	1	5	31		3	1		4	
Brachycentridae										
Brachcentrus	1	1	6	2		3	18	52	7	
Coleoptera										
Elmidae										
Norpus[2]	2						2			
Heterlimnius[2]	2	2								
Optioservus[2]	2						1			

Table C-1.—*Arkansas River Invertebrate Summary, June 1974*—Continued

Taxon	Tolerance class	Sampling stations EF-3	AR-1	AR-3	AR-4	AR-5	AR-9	AR-10	AR-7	AR-8
Diptera										
Tipulidae										
Tipula	2						2			
Psychedidae										
Pericoma	1	1								
Ceratopagonidae										
Palpomyia	2	1								
Simulidae										
Prosimulium[3]	2	1	25	23	7	1	1	1		
Rhagionidae										
Aterix	2							1	1	
Chironomidae										
Micropsectra	1	1							1	
Pseudodlamesa	1	8		1	1					
Criotopus	2	2				2	1			
Psectroclaoius	2	1								
Trichocladius	1			3		1	3			
Orthocladius	1	1				1				
Eukiefferiella	1			23				1		
Cardiocladius[2]	1		9	1		1				
Thienemanniella	1		5	1						
unidentified			1							
Hydracarina										
Spnerchonidae										
Spherchon[2]	1			2			1		3	
Total Number Taxa		17	10	9	2	10	13	6	8	1
Total Number Inds.		108	63	89	8	22	54	65	24	1
Percent class I		86	52	72	13	77	80	97	83	0
Percent class II		14	48	28	87	23	20	3	17	100
Percent class III		0	0	0	0	0	0	0	0	0
TCI'		1.86	1.52	1.72	1.13	1.77	1.80	1.97	1.83	1.0

Table C-1.—*Arkansas River Invertebrate Summary, June 1974*—Continued

Taxon	Tolerance class	Sampling stations								
		EF-3	AR-1	AR-3	AR-4	AR-5	AR-9	AR-10	AR-7	AR-8
DBAR		2.26	2.74	2.26	0.54	2.95	2.93	1.06	2.70	0
EQUIT		.38	.92	.72	.80	.83	.42	1.08	1.13	I

[1] Early instars, too small to identify to genus. Not included in biological index calculations.

[2] Tentative identification.

[3] Three pupae were positively identified as *Prosimulium*; larvae were considered *Prosimulum* although positive identification was not possible.

Table C-2.—*Arkansas River invertebrate summary, July 1974*

Taxon	Tolerance classs	Sampling stations							
		EF-5	AR-1	AR-4	AR-5	AR-6	AR-10	AR-7	AR-8
Ephemeroptera									
Baetidae									
Baetis	2	7	1	1	2		12	1	2
Ephemerella	1	2			18				
Plecoptera									
Pteronarcidae									
Pteronarcella	1		1		2				
Nemouridae									
Zapada	1	3							
Amphinemura	1		1		27				
Perlodidae									
Isoperla	1	1			1	1	5	2	7
Isogenus	1	2							
Chloroperlidae									
Alloperla	1	5	1		4	3	1	5	2
Trichoptera									
Hydropsychidae									
Arctopsyche	1		1			1			
Rhyacophilidae									
Rhyacophila	1	3	18	3	4				1
Brachycentridae									
Brachycentrus	1	1	5	2	7	5	19	1	5
Lepidostromatidae									
Lepidostoma[1]	1	2							
Limneplilidae									
Platycentropus[1]	1				2				
Diptera									
Rhagionidae									
Atherix	2					1			1
Simulidae									
Prosimulium[1]	2		4	1					28
Chironomidae									
Tribelos	1				1			7	
Pseudodiamesa	1	2	6		12		28	3	1

Table C-2.—*Arkansas River Invertebrate summary, July 1974*—Continued

Taxon	Tolerance class	Sampling stations							
		EF-5	AR-1	AR-4	AR-5	AR-6	AR-10	AR-7	AR-8
Cricoptopus	2	13	2	9			34	2	
Psectrocladius	2		1						1
Trichocladius	1	1					2	1	
Orthocladius	1	1							2
Eukiefferella	1	1	6	1			3		46
Cardiocladius	1								1
Thienemanniella	1	5	1					1	
Smitlia	2		1						
Paraphenocladius	2							1	
Total Number Inds.		47	51	7	90	12	104	24	97
Total Number Taxa		14	15	4	13	5	8	10	12
Percent class I		57.45	84.31	71.43	87.78	91.67	55.77	83.33	67.01
Percent class II		42.55	15.69	28.57	12.22	8.33	44.23	16.67	32.99
Percent class III		0	0	0	0	0	0	0	0
TCI′		1.5745	1.8431	1.7143	1.8778	1.9167	1.5577	1.8333	1.6701
DBAR		3.2889	3.1295	1.8424	2.9736	2.0546	2.3766	2.9176	2.2087
EQUIT		.995	.826	1.166	.848	1.100	.879	1.059	.516

[1] Tentative identification.

Table C-3.—*Arkansas River invertebrate summary, August 1974*

Taxon	Tolerance class	Sampling station										
		EF-3	EF-5	AR-1	AR-3	AR-4	AR-5	AR-6	AR-9	AR-10	AR-7	AR-8
Nematoda												
Genus 1	2			2								
Ephemeroptera												
Baetidae												
Baetis	2			24	16		1		14	3		
Ephemerella	1	2					1	1				
Heptageniidae												
Ironopsis	1				1							
Plecoptera												
Pteronarcidae												
Pteronarcella	1			1	7							
Nemouridae												
Amphinemura	1			1	4							
Perlodidae												
Archynopteryx	1		1		6				4			
Isoperla	1		1						1		1	
Chloroperlidae												
Alloperla	1	2	2	2	7	1					6	
Perlidae Acroncuria												1
Trichoptera												
Hydropsychidae												
Arctopsyche	1	1	1	11	1	1	24	5				4
Rhyacophilidae												
Rhyacoplula	1	2	2	17	8	21	5			1		
Brachycentridae												
Brachycentrus	1			10	8	9	20	5		21		4
Lepidostomatidae												
Lepidostoma	1				1					8		
Coleoptera												
Elmidae												
Heterlimnus	1	4	1				1					
Hallpidae*												
Genus 1	2										1	
Diptera												
Tipulidae												
Tipula	2	3	2									
Simulidae												
Prosimullum	2			19	1					2		

Table C-3.—*Arkansas River invertebrate summary, August 1974*—Continued

Taxon	Tolerance class	Sampling station										
		EF-3	EF-5	AR-1	AR-3	AR-4	AR-5	AR-6	AR-9	AR-10	AR-7	AR-8
Diptera—Continued												
Rhagionidae												
Atherix	2			1								1
Chironomidae												
Pseudodiamesa	1	1	4		2	1	84	1		2		
Cricotopus	2	1	2		1	2	39	1		1		1
Psectrocladius	2						3					
Orthocladius	1							1				1
Eukiefferiella	1			1			15	1			1	1
*Curdiocladius**	1		2		3	3						
*Smittia**	2					3						
Hydracarina												
Genus 2	1	1	2									
Total number Taxa		9	11	11	13	7	12	15	3	7	7	7
Total number Inds.		17	20	89	63	38	199	7	19	38	9	13
Percent class I		76.47	80.0	49.44	71.43	94.74	76.88	93.33	26.32	84.21	88.89	93.31
Percent class II		23.53	20.0	50.56	28.57	5.26	23.12	6.67	73.68	15.79	11.11	7.69
Percent class III		0	0	0	0	0	0	0	0	0	0	0
TCI′		1.7647	1.8000	1.4944	1.7143	1.9474	1.7688	1.9333	1.2632	1.8421	1.8889	1.9231
DBAR		2.9842	3.3219	2.7060	3.1707	1.8921	2.4907	2.3859	1.0215	1.9586	1.4466	2.4697
EQUIT		1.236	1.298	.821	.983	.6913	.640	.991	.810	.727	.853	1.080

Large amounts of moss present believed responsible for high numbers of Chironomids.

Adult Ephemeroptera and Plecoptera not included in counts. Specimens present were from drift.

*Tentative.

Table C-4.—*Arkansas River invertebrate summary, September 1974*

Taxon	Tolerance class	Sampling stations EF-3	EF-5	AR-1	AR-3	AR-4	AR-5	AR-6	AR-9	AR-10	AR-7	AR-8
Oligachaeta												
Lumbricidae												
Genus 1	2	2										
Tubificidae												
Genus 1	3	2										
Ephemeroptera												
Baetidae												
Baetis	2	3	2	26			3	13	12	15	2	5
Centroptilum	2				1							
Ephemerella	1	10	2									
Plecoptera												
Pteronarcidae												
Pteronarcella	1			2	12		10	5		7		1
Perlidae												
Acroneuria	1											3
Perlodidae												
Aroynopteryx	1		11	1	1	2		14		7	3	
Isoperla	1	4			1	8		1	2			3
Chloroperlidae												
Alloperla	1	7		7	7	4	12	4	16		1	1
Trichoptera												
Hydropsychidae												
Arctopsyche	1		3	10		1	35	116	1	1	6	1
Rhyacophilidae												
Rhyacophila	1	3	12		6	8	8		1			
Brachycentridae												
Brachycentrus	1			16	18	9	16	26		31	10	3
Coleoptera												
Elmidae												
Heterlimnius	1	2	6				1	2				
Diptera												
Tipulidae												
Tipula	2	1	2									
Dicranota												
Erioptera	2	1	1									

Table C-4.—*Arkansas River invertebrate summary, September 1974*—Continued

Taxon	Tolerance class	Sampling stations										
		EF-3	EF-5	AR-1	AR-3	AR-4	AR-5	AR-6	AR-9	AR-10	AR-7	AR-8
Diptera—Continued												
Simulidae												
Prosimulium	2						1	5		1	3	
Empididae												
Roederiodes	2					1						
Chironomidae												
Micropsectra	1	1										
Pseudodiamesa	1					2	4	3				
Cricotopus	2	6					2	1	1			
Trichocladius	1						1					
Orthocladius	1	3										
Eukiefferiella	1					1	2					1
Cardiocladius	1					4						
Total number Taxa		14	9	7	7	9	12	11	5	7	6	8
Total number Inds.		46	46	63	50	40	87	202	17	63	25	18
Percent class I		65.22	89.13	58.73	98.00	97.50	93.10	90.59	23.53	74.60	80.00	72.22
Percent class II		30.43	10.87	41.27	2.00	2.50	6.90	9.41	76.47	25.40	20.00	27.78
Percent class III		4.35	0	0	0	0	0	0	0	0	0	0
TCI′		1.6087	1.8913	1.5873	1.9800	1.9750	1.9310	1.9059	1.2353	1.7460	1.8000	1.7222
DBAR		3.4226	2.7629	2.1506	2.3321	2.6332	2.7016	2.1477	1.4393	1.9854	2.2343	2.7325
EQUIT		1.098	1.048	.844	.972	.951	.750	.536	.678	.744	.052	1.152

Table C-5.—*Arkansas River invertebrate summary, October 1974*

Taxon	Tolerance class	Sampling stations										
		EF-3	EF-5	AR-1	AR-3	AR-4	AR-5	AR-6	AR-9	AR-10	AR-7	AR-8
Ephemeroptera												
Baetidae												
Baetis	2						1	2		6		1
Ephemerella	1		1	1	1							
Plecoptera												
Pteronarcidae												
Pteronarcella	1			2	42		16	15	5	14	3	
Nemouridae Zapada	1				1							
Perlidae												
Acroneuria	1						1					1
Perlodidae												
Arcynopterynx	1		4	1	1	3	2	6		4		4
Isoperla	1	1		5	10	2	1					2
Chloroperlidae												
Alloperla (early instars)	1	3	9	5		51	56	5	3	1	1	2
Trichoptera												
Hydropsychidae												
Arctopsyche	1			2	2		12	54	3	1	7	1
Rhyacophilidae												
Rhyacophila	1		3	10	8	1	13	2			1	
Agapetus	1									1		
Brachycentridae												
Brachycentrus (early instars)	1			3	6	18	2	42	5	5	1	6
Coleoptera												
Elimidae												
Heterlimnius	1	2	1							1		
Diptera												
Tipulidae												
Tipula	2	4	3									
Hexatoma	2		1									
Dicranota	2	5										
Rhagionidae												
Atherix	2									2		
Simulidae												
Prosimulium	2										1	

Table C-5.—*Arkansas River invertebrate summary, October 1974*—Continued

Taxon	Tolerance class	Sampling stations										
		EF-3	EF-5	AR-1	AR-3	AR-4	AR-5	AR-6	AR-9	AR-10	AR-7	AR-8
Diptera—Continued												
Ceratopogonidae												
Polpomyia	2		1									
Chironomidae												
Pseudodiamesa	1			2			2	1				
Tribelos	1	19	1		27							
Parachironomus	2	1										
Cricotopus	2			2			1					2
Eukiefferiella	1	1										
Unidentified	2					1						
Total number Taxa		8	9	10	9	6	11	8	4	9	6	8
Total number Inds.		36	24	33	98	76	107	128	16	35	14	19
Percent class I		75.00	79.17	93.94	100.0	98.68	98.13	97.66	100.0	77.14	92.86	84.21
Percent class II		25.00	20.83	6.06	0	1.32	1.87	2.34	0	22.86	7.14	15.79
Percent class III		0	0	0	0	0	0	0	0	0	0	0
TCI'		1.7500	1.7917	1.9394	2.0000	1.9868	1.9713	1.9766	2.0000	1.7714	1.9286	1.8421
DBAR		2.1956	2.6667	2.9476	2.2312	1.3649	2.1963	2.0803	1.9544	2.5458	2.0640	2.6948
EQUIT		.765	.975	1.082	.700	.531	.557	.701	1.268	.888	924	1.119

APPENDIX D

1971-73 Invertebrate Data

Table D-1.—*Organism list—Stream stations*

Common	Order	Family	Genus	Number
		Station AR-1—2 Surber—10/22/71		
A Caddisfly	Trichoptera	Brachycentridae	*Brachycentrus*	3
B Caddisfly	Trichoptera	Hydropsychidae	*Hydropsyche*	11
A Mayfly	Ephemeroptera	Heptageniidae		1
Roundworm	Nematoda			1
A Stonefly	Plecoptera	Perlodidae	*Isoperla*	3
C Caddisfly	Trichoptera	Rhyacophilidae	*Rhyacophila*	2
		Station AR-1—Art. Sub.—6/27/73		
Blackfly	Diptera	Simuliidae		13
A Caddisfly	Trichoptera	Hydropsychidae	*Hydropsche*	16
B Caddisfly	Trichoptera	Brachycentridae	*Brachycentrus*	1
C Caddisfly	Trichoptera	Rhyacophilidae	*Rhyacophila*	3
Midge	Dipera	Tendipedidae		4
Stonefly	Plecoptera	Taeniopteryginae	*Brachyptera*	1
A Mayfly	Ephemeroptera	Baetidae		8
B Mayfly	Ephemeroptera	Baetidae	*Ephemerella*	14
C Mayfly	Ephemeroptera	Heptageniidae	*Stenonema*	2
		Station AR-1—Art. Sub.—7/31/73		
A Caddisfly	Trichoptera	Brachycentridae	*Brachycentrus*	2
B Caddisfly	Trichoptera	Rhyacophilidae	*Rhyacophila*	3
Blackfly	Diptera	Simuliidae		2
Midge	Diptera	Tendipedidae		9
Mayfly	Ephemeroptera	Baetidae		4
Stonefly	Plecoptera	Preemergent adult		1
		Station AR-1—Art. Sub.—9/10/73		
A Caddisfly	Trichoptera	Brachycentridae	*Brachycentrus*	59
Blackfly	Diptera	Simuliidae		28
Midge	Diptera	Tendipedidae		5
B Caddisfly	Trichoptera	Rhyacophilidae	*Rhyacophila*	4
C Caddisfly	Trichoptera	Hydropsychidae	*Hydropsyche*	5
Stonefly	Plecoptera	Taeniopteryginae	*Brachyptera*	1
		Station AR-3—2 Surber—8/3/71		
A Caddisfly	Trichoptera	Rhyacophilidae	*Rhyacophila*	4
B Caddisfly	Trichoptera	Brachycentridae	*Brachycentrus*	1
A Mayfly	Ephemeroptera	Baetidae		12
B Mayfly	Ephemeroptera	Heptageniidae		2
A Stonefly	Plecoptera	Pteronarcidae	*Pteronarcella*	2
B Stonefly	Plecoptera	Taeniopteryginae	*Brachytera*	1
C Mayfly	Ephemeroptera	Heptageniidae	*Stenonema*	1
D Mayfly	Ephemeroptera	Baetidae	*Ephemecella*	1

Table D-1.—*Organism list—Stream stations*—Continued

Common	Order	Family	Genus	Number
	Station AR-3—3 Surber—10/20/71			
A Caddisfly	Trichoptera	Brachycentridae	*Brachycentrus*	144
B Caddisfly	Trichoptera	Hydropsychidae	*Hydropsyche*	13
A Mayfly	Ephemeroptera	Heptageniidae	*Stenonema*	2
B Mayfly	Ephemeroptera	Baetidae		3
A Stonefly	Plecoptera	Perlodidae	*Isoperla*	3
B Stonefly	Plecoptera	Pteronarcidae	*Pteronarcella*	4
	Station AR-3—3 Surber—9/26/72			
A Stonefly	Plecoptera	Pteronarcidae	*Pteronarcella*	3
B Stonefly	Plecoptera	Perlodidae	*Isoperla*	3
A Caddisfly	Trichoptera	Brachycentridae	*Brachycentrus*	21
B Caddisfly	Trichoptera	Hydropsychidae	*Hydropsyche*	4
C Caddisfly	Trichopteria	Rhyacophiliidae	*Rhyacophila*	2
A Mayfly	Ephemeroptera	Heptageniidae	*Stenonema*	9
B Mayfly	Ephemeroptera	Baetidae		6
D Caddisfly	Trichoptera	Phryganeidae	*Ptilostomis*	2
Roundworm	Nematoda			4
Cranefly	Diptera	Tipulidae		1
	Station AR-3—Art. Sub.—7/31/73			
A Caddisfly	Trichoptera	Brachycentridae	*Brachycentrus*	12
B Caddisfly	Trichoptera	Hydropsychidae	*Hydropsyche*	3
C Caddisfly	Trichoptera	Rhyacophilidae	*Rhyacophila*	4
Stonefly	Plecoptera	Pteronarcidae	*Pteronarcella*	3
Midge	Diptera	Tendipedidae		4
	Station AR-3—Art. Sub.—9/11/73			
A Caddisfly	Trichoptera	Brachycentridae	*Brachycentrus*	4
B Caddisfly	Trichoptera	Hydropsychidae	*Hydropsyche*	1
Mayfly	Ephemeroptera	Baetidae		2
Blackfly	Diptera	Simuliidae		2
	Station AR-4—2 Surber—8/3/71			
Caddisfly	Trichoptera	Brachycentridae	*Brachycentrus*	1
Mayfly	Ephemeroptera	Baetidae		2
	Station AR-4—Art. Sub.—7/31/73			
A Caddisfly	Trichoptera	Brachycentridae	*Brachycentrus*	19
B Caddisfly	Trichoptera	Rhyacophilidae	*Rhyacophila*	1
	Station AR-4—Art. Sub.—9/10/73			
Caddisfly	Trichoptera	Brachycentridae	*Brachycentrus*	9

Table D-1.—*Organism list—Stream stations*—Continued

Common	Order	Family	Genus	Number
		Station AR-5–2 Surber–8/4/71		
A Caddisfly	Plecoptera	Brachycentridae	*Brachycentrus*	10
B Caddisfly	Plecoptera	Hydropsychidae	*Hydropsyche*	1
Mayfly	Ephemeroptera	Baetidae		4
Midge	Diptera	Tendipedidae		1
		Station AR-5–3 Surber–9/26/72		
A Caddisfly	Trichoptera	Brachycentridae	*Brachycentrus*	30
B Caddisfly	Trichoptera	Hydropsychidae	*Hydropsyche*	32
C Caddisfly	Trichoptera	Rhyacophilidae	*Rhyacophila*	1
		Station AR-5–Art. Sub.–6/27/73		
A Caddisfly	Trichoptera	Brachycentridae	*Brachycentrus*	7
B Caddisfly	Trichoptera	Hydropsychidae	*Hydropsyche*	8
Stonefly	Plecoptera	Pteronarcidae	*Pteronarcella*	2
Cranefly	Diptera	Tipulidae		2
		Station AR-5–Art. Sub.–7/31/73		
A Caddisfly	Trichoptera	Brachycentridae	*Brachycentrus*	31
B Caddisfly	Trichoptera	Hydropsychidae	*Hydropsyche*	12
C Caddisfly	Trichoptera	Rhyacophilidae	*Rhyacophila*	2
Midge	Diptera	Tendipedidae		4
Mayfly	Ephemeroptera	Baetidae	*Ephemerella*	1
		Station AR-5–Art. Sub.–9/10/73		
Blackfly	Diptera	Simuliidae		1
		Station AR-6–3 Surber–10/21/71		
Caddisfly	Trichoptera	Brachycentridae	*Brachycentrus*	13
Stonefly	Plecoptera	Pteronarcidae	*Pteronarcella*	2
		Station AR-7–2 Surber–8/3/71		
Caddisfly	Trichoptera	Brachycentridae	*Brachycentrus*	6
Mayfly	Ephemeroptera	Baetidae		2
		Station AR-7–3 Surber–9/26/72		
A Caddisfly	Trichoptera	Brachycentridae	*Brachycentrus*	42
B Caddisfly	Trichoptera	Hydropsychidae	*Hydropsyche*	3
Mayfly	Ephemeroptera	Baetidae	*Choroterpes*	3
Midge	Diptera	Tendipedidae		2
		Station AR-7–Art. Sub.–7/31/73		
Caddisfly	Trichoptera	Brachycentridae	*Brachycentrus*	712
Midge	Diptera	Tendipedidae		1

Table D-1.—*Organism list—Stream stations*—Continued

Common	Order	Family	Genus	Number
		Station AR-7—Art. Sub.—9/10/73		
Caddisfly	Trichoptera	Brachycentridae	*Brachycentrus*	244
		Station AR-8—2 Surber—8/3/71		
Caddisfly	Trichoptera	Brachycentridae	*Brachycentrus*	22
Mayfly	Ephemeroptera	Baetidae	*Choroterpes*	26
Snipefly	Ciptera	Rhagionidae	*Atherix*	3
		Station AR-8—3 Surber—9/26/72		
A Caddisfly	Trichoptera	Brachycentridae	*Brachycentrus*	9
B Caddisfly	Trichoptera	Brachycentridae	*Brachycentrus*	9
Snipefly	Diptera	Rhagionidae	*Atherix*	4
Blackfly	Diptera	Simuliidae		1
A Stonefly	Plecoptera	Pteronarcidae	*Pteronarcella*	2
B Stonefly	Plecoptera	Perlodidae	*Isoperla*	4
Mayfly	Ephemeroptera	Baetidae	*Choroterpes*	16
		Station AR-8—Art. Sub.—6/26/73		
A Caddisfly	Trichoptera	Brachycentridae	*Brachycentrus*	31
B Caddisfly	Trichoptera	Hydropsychidae	*Hydropsyche*	1
Snipefly	Diptera	Rhagionidae	*Atherix*	3
Cranefly	Diptera	Tipulidae		1
Stonefly	Plecoptera	Perlodidae	*Isoperla*	4
		Station AR-8—Art. Sub.—7/31/73		
Caddisfly	Trichoptera	Brachycentridae	*Brachycentrus*	8
Snipefly	Diptera	Rhagionidae	*Atherix*	3
		Station AR-8—Art. Sub.—9/10/73		
Caddisfly	Trichoptera	Brachycentridae	*Brachycentrus*	35

CONVERSION FACTORS—BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, E 380-68) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given in the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg, that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Where approximate or nominal English units are used to express a value or range of values, the converted metric units in parentheses are also approximate or nominal. Where precise English units are used, the converted metric units are expressed as equally significant values.

Table I

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
LENGTH		
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
Inches	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
Feet	0.3048 (exactly)*	Meters
Feet	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
Miles	1.609344 (exactly)	Kilometers
AREA		
Square inches	6.4516 (exactly)	Square centimeters
Square feet	*929.03	Square centimeters
Square feet	0.092903	Square meters
Square yards	0.836127	Square meters
Acres	*0.40469	Hectares
Acres	*4,046.9	Square meters
Acres	*0.0040469	Square kilometers
Square miles	2.58999	Square kilometers
VOLUME		
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
CAPACITY		
Fluid ounces (U.S.)	29.5737	Cubic centimeters
Fluid ounces (U.S.)	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
Liquid pints (U.S.)	0.473166	Liters
Quarts (U.S.)	*946.358	Cubic centimeters
Quarts (U.S.)	*0.946331	Liters
Gallons (U.S.)	*3,785.43	Cubic centimeters
Gallons (U.S.)	3.78543	Cubic decimeters
Gallons (U.S.)	3.78533	Liters
Gallons (U.S.)	*0.00378543	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
Gallons (U.K.)	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	*764.55	Liters
Acre-feet	*1,233.5	Cubic meters
Acre-feet	*1,233,500	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb)	64.79891 (exactly)	Milligrams
Troy ounces (480 grains)	31.1035	Grams
Ounces (avdp)	28.3495	Grams
Pounds (avdp)	0.45359237 (exactly)	Kilograms
Short tons (2,000 lb)	907.185	Kilograms
Short tons (2,000 lb)	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms
FORCE/AREA		
Pounds per square inch	0.070307	Kilograms per square centimeter
Pounds per square inch	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
Pounds per square foot	47.8803	Newtons per square meter
MASS/VOLUME (DENSITY)		
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
Pounds per cubic foot	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.)	7.4893	Grams per liter
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
BENDING MOMENT OR TORQUE		
Inch-pounds	0.011521	Meter-kilograms
Inch-pounds	1.12985×10^6	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
Foot-pounds	1.35582×10^7	Centimeter-dynes
Foot-pounds per inch	5.4431	Centimeter-kilograms per centimeter
Ounce-inches	72.008	Gram-centimeters
VELOCITY		
Feet per second	30.48 (exactly)	Centimeters per second
Feet per second	0.3048 (exactly)*	Meters per second
Feet per year	*0.965873×10^{-6}	Centimeters per second
Miles per hour	1.609344 (exactly)	Kilometers per hour
Miles per hour	0.44704 (exactly)	Meters per second
ACCELERATION*		
Feet per second^2	*0.3048	Meters per second^2
FLOW		
Cubic feet per second (second-feet)	*0.028317	Cubic meters per second
Cubic feet per minute	0.4719	Liters per second
Gallons (U.S.) per minute	0.06309	Liters per second
FORCE*		
Pounds	*0.453592	Kilograms
Pounds	*4.4482	Newtons
Pounds	*4.4482×10^5	Dynes

Table II—Continued

Multiply	By	To obtain
WORK AND ENERGY*		
British thermal units (Btu)	*0.252	Kilogram calories
British thermal units (Btu)	1,055.06	Joules
Btu per pound	2.326 (exactly)	Joules per gram
Foot-pounds	*1.35582	Joules
POWER		
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts
HEAT TRANSFER		
Btu in./hr ft^2 degree F (k, thermal conductivity)	1.442	Milliwatts/cm degree C
Btu in./hr ft^2 degree F (k, thermal conductivity)	0.1240	Kg cal/hr m degree C
Btu ft/hr ft^2 degree F	*1.4880	Kg cal m/hr m^2 degree C
Btu/hr ft^2 degree F (C, thermal conductance)	0.568	Milliwatts/cm^2 degree C
Btu/hr ft^2 degree F (C, thermal conductance)	4.882	Kg cal/hr m^2 degree C
Degree F hr ft^2/Btu (R, thermal resistance)	1.761	Degree C cm^2/milliwatt
Btu/lb degree F (c, heat capacity)	4.1868	J/g degree C
Btu/lb degree F	*1.000	Cal/gram degree C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
Ft^2/hr (thermal diffusivity)	*0.09290	M^2/hr
WATER VAPOR TRANSMISSION		
Grains/hr ft^2 (water vapor) transmission)	16.7	Grams/24 hr m^2
Perms (permeance)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	*304.8	Liters per square meter per day
Pound-seconds per square foot (viscosity)	*4.8824	Kilogram second per square meter
Square feet per second (viscosity)	*0.092903	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	*35.3147	Millicuries per cubic meter
Milliamps per square foot	*10.7639	Milliamps per square meter
Gallons per square yard	*4.527219	Liters per square meter
Pounds per inch	*0.17858	Kilograms per centimeter

ABSTRACT

Portions of the upper Arkansas River of Colorado are affected by heavy metal-laden inflows which are remnant of the mining era of the late 1800's. The heavy metal pollution results in a significantly impoverished stream biota in several areas. Historically, river flows which dilute heavy metal concentrations were not as high as those occurring since transmountain diversions began, so it is possible that the concentration of heavy metals in the river was higher in the past. Nevertheless, based on studies of water quality, accumulation of heavy metals in river sediments, species diversity indices, fish populations, and concentration of heavy metals in aquatic organisms at 11 sampling stations in an 18-mile (28.968-km) reach, conditions for aquatic life in the upper Arkansas River of Colorado are described as poor. Within this reach of river, there are three major sources of heavy metal inflow: Leadville Drain, California Gulch, and diffuse flows in an area between the inflows of Lake Fork and Lake Creek. California Gulch is by far the largest contributor of heavy metals. In each instance at varying distances from the pollution source, there is a downstream inflow of relatively clean water. These clean water inflows in two of the three cases result, in part, from the transmountain diversion. In the future, most of these two freshening flows will be diverted, which could cause the heavy metal inflow from California Gulch and Leadville Drain to be carried along a greater stretch of the Arkansas River. (56 ref)

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DESCRIPTORS—/ water pollution/ mine drainage/ *heavy metals/ *water pollution sources/ chemical wastes/ water quality/ fish populations/ aquatic life/ mining/ water analysis/ stream pollution/ water pollution effects/ bibliographies
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